365/26

PRINCIPLES

OF

HUMAN PHYSIOLOGY.

BY

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Sixth Edition.

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AUTHOR'S PREFACE.

THE Fifth Edition of his "Principles of Human Physiology" having been for some years out of print, and the Author having been repeatedly urged by his Publisher to prepare a Sixth, he for some time cherished the hope of accomplishing this, so soon as he should have completed a series of original researches which he felt himself pledged to carry through. On applying himself to the task, however, he found that insuperable difficulties lay in the way of his satisfactory performance of it. For having long since relinquished, on his appointment to the post he at present occupies, the duties of a Teacher of Physiology, and having consequently ceased to feel it incumbent upon him to keep up with the progress of the science in detail, he found that the mass of new material which had been accumulated by the industry of inquirers in every one of its departments was far greater than it lay within his capacity to systematize; the time and working power left at his disposal by the requirements of his official position being extremely limited. Feeling it now to be his duty, moreover, to devote such power as remains to him rather to the extension of the boundaries of knowledge by researches of his own, than to the co-ordination of the results elaborated by others, he became not only willing but desirous to retire from the field he had so long occupied, and to leave the cultivation of it to men of a younger generation.

As it was represented to the Author, however, that other interests than his own required that this Treatise should be kept before the public, he has thought it right to acquiesce in the proposition of his Publisher that it should be reproduced by a competent Editor, upon whom should rest the entire charge of accommodating the work to the present state of Physiological Science; and having been fortunate enough to obtain for this purpose the services of a gentleman in whose ability and conscientious zeal he felt great confidence, he has left the preparation of this

Edition most unreservedly in his hands. The First and Second Chapters, however, having been prepared by the Author before the necessity of relinquishing the charge of the work had been forced upon him, he placed these in Mr. Power's possession, to be employed or put aside at his discretion; but with this exception he holds himself exempt from responsibility in regard either to the scientific character or the literary execution of the present issue, in which he feels it right to add that he has no pecuniary interest whatever.

The extent of the additions which the Editor found it desirable to make in various parts of the volume, joined to the objection of the Publisher to any material increase of its bulk, caused the question to be submitted to the Author in what manner these two conditions could best be reconciled; and he could not see how the difficulty was to be met in any other way, than by the omission of the outline of Psychology which had been given in the last two Editions under the title "Functions of the Cerebrum." To this omission he has been the less indisposed, since on the one hand he has felt it doubtful whether such an outline has a proper claim to a place in a treatise on Physiology; whilst, on the other, he is not without hope that he may find himself able at some future time to expand this outline into a Manual, which may be of value to that increasing class of Students who desire to pursue their inquiry into the Powers and Operations of the Mind upon the basis of what is known of the Physiological action of its material instrument, the Nervous System.

University of London,
September 1, 1864.

EDITOR'S PREFACE.

In undertaking, in the autumn of 1861, the preparation of the Sixth Edition of Dr. Carpenter's "Principles of Human Physiology," the Editor was scarcely aware of the long and laborious nature of the task upon which he has since been unceasingly engaged. He soon found that in the few years which had elapsed since the appearance of the last Edition (in 1855) a very large mass of observations, indicative of the increasing attention bestowed upon the Science of Physiology in this country, had accumulated. He soon found also, that notwithstanding the numerous and valuable essays upon various branches of Physiology contributed by English writers, no accurate or comprehensive representation of the present state of the science could be given without frequent reference to the results obtained by German inquirers, the acquisition of whose language, as far as was requisite for practical purposes, he made his first care. There can, indeed, be little question that Germany is the centre from which the extension and development of modern Physiology chiefly proceeds. The time and means at the disposal of her *savans* (many of whom are occupied exclusively in the pursuit of this science) are considerably greater than those possessed by English experimenters, who are, almost without exception, also engaged in practice. It is not surprising then that the number of original workers in Germany should greatly exceed those of this country, nor that they should be able to support a much larger number of journals more or less devoted to Physiology. But in the innumerable experiments of which the results are recorded in these periodicals, a new "distemper of learning" arises, scarcely less opposed to the discovery of truth than those "cobwebs of learning admirable for the firmness of the thread and work, but of no substance or profit," which were denounced by Lord Bacon as proceeding from the working of the Mind upon itself, and which arose at a period when experiment was almost wholly neglected: for from the extraordinary variability of the conditions of Life, and from the singularly different ability of observers in eliminating sources of error, and in truly recording their observations, conclusions of an almost contradictory character are frequently obtained. A friend of the Editor, in discussing this subject with him at the outset, reminded him that, as the present work was of a purely educational character, it would be unwise to render it in any way controversial by giving a full description of opposite or widely divergent opinions, which would only serve to perplex, without conveying instruction to, the student. On the other hand, the Editor felt it might fairly be urged that as in those instances where different conclusions had been drawn from experiments of an essentially similar character, it was probable that each contained the elements of truth, the best plan to be pursued was to exhibit, as succinctly as possible, the more important views held by the highest authorities, and thus enable the reader to select that which seemed to be the most tenable. Where practicable, the latter of the two courses has been preferred. In some instances, however, considerations of space have rendered it impossible; and he would here refer in particular to the New Theory of Muscular Action promulgated by Dr. Radcliffe, which he has not thought sufficiently established to accept unreservedly, though he fully acknowledges the ability with which it is sustained.

In comparing the present with the last Edition, it will be found that whilst the general plan of the work has been strictly followed, considerable additions have been made in almost every Chapter. The Sections on the Functions of the Cerebrum, now omitted, occupied 140 pages; yet the new material which has been introduced has again brought up the volume to within a few pages of its original size.

In the Third Chapter, "On Food and the Digestive Process," considerable additions have been made to the Section treating of the Saliva; and the results of the experiments of Bernard, Adrian, and Eckhard, on the influence of the Nervous System upon this secretion, have been introduced. In that devoted to the Gastric Juice, the experiments of Brücke on the action of this fluid on Fibrin and Albumen are detailed, together with those of Meissner on the formation of Peptones and Parapeptones. The various opinions that are now held in regard to the function of the Pancreatic Juice and of the Bile are fully noticed, and a short account of the Gases of the Intestines has been given, according to the recent researches of Ruge and Planer. In the Chapter on Absorption, the structure of the Epithelial Cells of the Villi has been somewhat minutely described, and a brief description of the process of Osmosis introduced. The description of the Absorbent Glands has been chiefly drawn from the elaborate works of Teichmann and Frey.

In the Chapter on the Blood, whilst the details of the structure of the Corpuscles and of the Crystals of the Blood have been extended, it has been thought expedient to reduce the space in the previous Editions devoted to the consideration of its Chemical characters, both in health and disease, since it has been shown by Von Gorup-Besanez that but little reliance can be placed on any of the modern methods of analysis. A separate Section has been written upon the Pneumatology of the Blood.

In the Section upon the Circulation, the chief results obtained by Dr. Halford on the sounds of the Heart, by Dr. Edward Smith on the frequency of its action, and by M. Marey upon the nature of the Pulse as indicated by the Sphygmograph (an instrument which will probably hereafter be largely employed in the diagnosis of disease), have been fully given.

The Chapter on Respiration has been increased by the introduction of the observations of Rosenthal (essentially confirmatory of those of Dr. Reid) on the nervous influence conveyed by the Pneumogastric Nerves and their branches, and also of the careful and prolonged investigations of Dr. Ed. Smith, upon the circumstances affecting the elimination of Carbonic acid.

An entirely new Section has been added to the Chapter on Nutrition, entitled the "Balance of the Vital Economy," in which it has been attempted to give an outline, founded on the observations of Bischoff and Voit and of Ranke, of the effects of different modes of alimentation upon the general nutrition of the body, and further by comparing the Egesta with the Ingesta, to obtain some insight into the conditions affecting the distribution of the constituents of the food to the various tissues, and the changes which they undergo in their passage through the system.

In the Chapter on Secretion, a Section on the Glycogenic function of the Liver has been added, containing an account of the observations of Bernard, Pavy, Rouget, and others; and free use has been made of Dr. Parkes's work on the Urine, to render the Section on that subject more perfect.

The contradictory, or at least at present irreconcileable, results above alluded to as obtained by different experimenters, are nowhere more conspicuous than in the numerous treatises that have appeared within the last few years upon the Nervous System. The investigations of Mr. Lockhart Clarke on the structure, and of MM. Brown-Séquard and Schiff on the functions of the principal divisions of the Cranio-spinal Axis, have been chiefly followed; whilst a special Section has been appended, containing a short *resumé* of the researches of Pflüger on the influence of Electrical Currents on Motor Nerves,—not on account of any practical importance that as yet belongs to them, but to show the extent and exactitude to which observation has attained in this difficult branch of inquiry; and to furnish the English reader with a sketch, however slight, of a subject that occupies a very large space in all the modern foreign works on Physiology. Various additions will be found in the Sections on Special Sense, the more important being Helmholtz' theory of Sound, and the recent advances that have been made in the knowledge of the phenomena accompanying the Accommodation of the Eye.

The Chapter on the structure and functions of Muscular Tissue has been considerably extended. Several of the paragraphs have, however, been drawn with but slight alteration from the Fourth Edition of the present work.

Lastly, in the Chapter on Generation and Development, the instructive lectures of Mr. Huxley, lately delivered at the College of Surgeons, and the special treatise of Kölliker on this subject, have been chiefly employed as guides.

The number of Woodcuts has been increased from 156 to 206, and several of the old ones have been replaced by new.

The Editor is desirous of taking this opportunity of thanking Mr. Lockhart Clarke, Mr. Parker, Mr. Gulliver, and Dr. Edward Smith, for much information most obligingly communicated. To Mr. L. Clarke he is in an especial manner indebted for his kindness in lending the Sections of the Medulla Oblongata, from which the Editor drew the sketches introduced into the text.

Though Dr. Carpenter, as stated in his foregoing Preface, has had no share in the preparation of the present Edition, with the exception of the first two Chapters, the Editor would be ungrateful were he not to acknowledge the great benefit he has derived in various ways from Dr. Carpenter's literary experience, the advantage of which has always been freely accorded to him. In conclusion, the Editor will feel satisfied if it is thought by those competent to form a judgment on such a subject, that in passing through his hands the work has not fallen from the high position amongst systematic treatises on Physiology, which it has hitherto been admitted to hold.

3, GROSVENOR TERRACE, BELGRAVE ROAD,
September, 1864.

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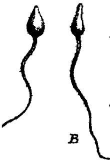

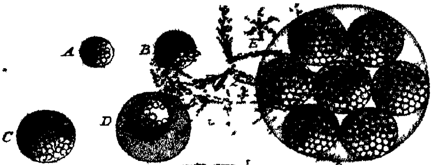

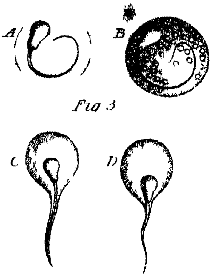

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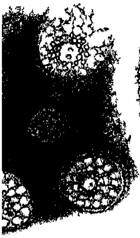

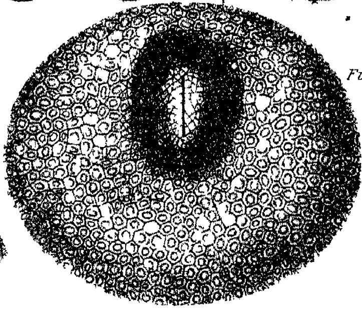

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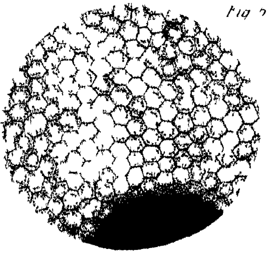

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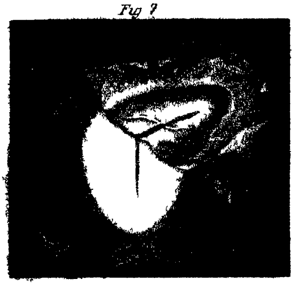

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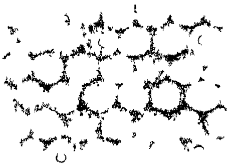

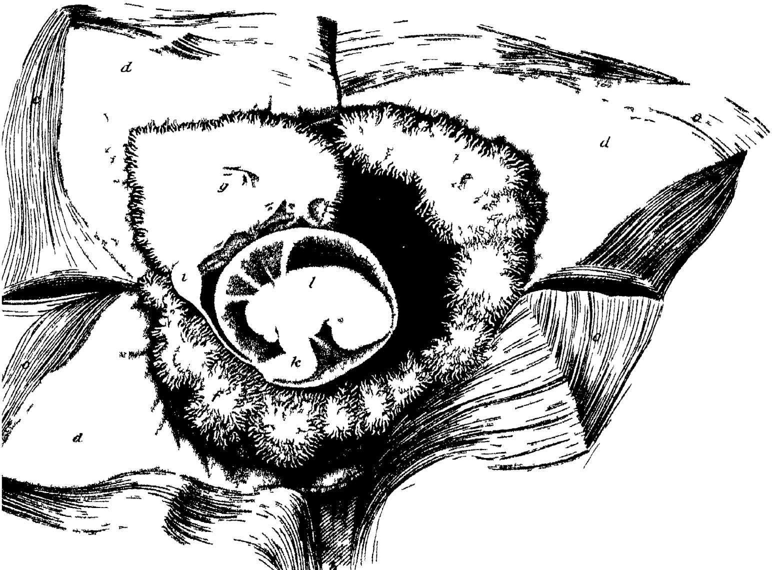

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PLATE I.

FIG.

1. Spermatozoa of Man; A, viewed on the surface; B, viewed edgeways (§ 720).

2. Vesicles of evolution from the seminal fluid of the Dog; A, B, C, single vesicles of different sizes; D, single vesicle within its parent-cell; E, parent-cell enclosing seven vesicles of evolution (§ 721).

3. Development of Spermatozoa within the vesicles of evolution; A, B, vesicles containing spermatozoa in process of formation; C, D, spermatozoa escaping from the vesicles (§ 721).

[The three preceding figures are after Wagner and Leuckardt ("Cyclop. of Anatomy and Physiology," Art. 'Semen').]

4. Thin slice of the ovarium of a Sow three weeks old, showing the Graafian vesicles or ovisacs imbedded in a fibro-cellular stroma. The ovisacs are filled with cells, in the midst of which one large one may be specially distinguished; this, which is the germinal vesicle, is surrounded by minute granules, which constitute the first indication of the yolk (§ 728).

5. Ovum of a Rabbit, showing the vitelline mass almost entirely converted into distinct cells, of which those at the surface are pressed against each other and against the zona pellucida, so as to assume a hexagonal form. The dark portion consists of a mass of vitelline spheres, which has not undergone this conversion (§ 766).

6. Ovum of the Rabbit, seven days after impregnation, viewed on a black ground. The outer membrane is the chorion, on which are seen incipient villosities. Within this is the *blastodermic vesicle*, at the summit of which is the projection formed by the *area germinativa;* and from this, the mucous layer of the germinal membrane is seen to extend over about one-third of the surface of the contained yolk (§ 766).

7. Portion of the germinal membrane, taken from the *area germinativa*, to show the two layers of which it is composed; the *serous*, or animal layer, is turned back, so as to show the *mucous* or vegetative layer *in situ.* In the latter is seen the *primitive trace* (§ 766).

8. Portion of the *serous* layer of the germinal membrane, highly magnified; showing that it is made-up of nucleated cells, united by intercellular substance, and filled with minute molecules (§ 766).

FIG.

9. Portion of the *mucous* layer of the germinal membrane, highly magnified; showing that it is made-up of cells, whose borders are more distinct and more closely applied to each other than those of the serous layer, and whose contents are more transparent (§ 766).

[The six preceding figures are after Bischoff ("Entwickelungsgeschichte der Saugethiere," &c. (1842), — "des Kaninchen-eies" (1842), — "des Hunde-eies" (1845).]

10. Gravid Uterus of a Woman who had committed suicide in the seventh week of pregnancy, laid open:—*a*, os uteri internum; *b*, cavity of the cervix; *c*, *c*, *c*, *c*, the four flaps of the body of the uterus turned back; *d*, *d*, *d*, inner surface of uterine decidua; *e*, *e*, decidua reflexa; *f*, *f*, external villous surface of the chorion; *g*, internal surface of the chorion; *h*, amnion; *i*, umbilical vesicle; *k*, umbilical cord; *l*, embryo; *m*, space between chorion and amnion (§§ 741–746, and 767–769). [After Wagner ("Icones Physiologicæ").]

PLATE II.

11. Uterine Ovum of Rabbit, showing the Area Pellucida, with the primitive trace (§§ 763, 767).

12. More advanced Ovum, showing the incipient formation of the Vertebral column, and the dilatation of the primitive groove at its anterior extremity (§§ 767, 783, 790, 791).

13. More advanced Embryo, seen on its ventral side, and showing the first development of the Circulating apparatus. Around the Vascular Area is shown the terminal sinus, *a*, *a*, *a*. The blood returns from this by two superior branches, *b*, *b*, and two inferior, *c*, *c*, of the omphalo-mesenteric veins, to the heart, *d*; which is, at this period, a tube curved on itself, and presenting the first indication of a division into cavities. The two aortic trunks appear, in the abdominal region, as the inferior vertebral arteries, *e*, *e*; from which are given-off the omphalo-mesenteric arteries, *f*, *f*, which form a network that distributes the blood over the vascular area. In the cephalic region are seen the anterior cerebral vesicles, with the two ocular vesicles, *g* (§§ 769–772).

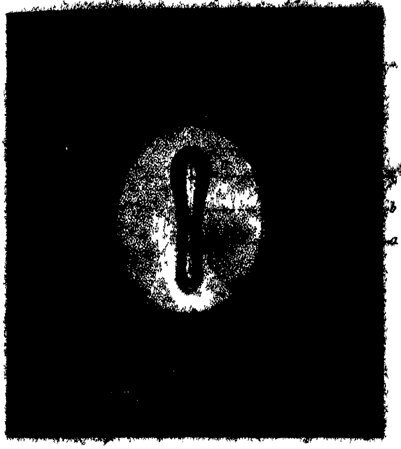
[The three preceding figures are from the works of Bischoff previously cited.]

PLATE III.

(To face page 23.)

Comparative View of the Skeleton of Man, and of that of the Orang Outan. [After Owen ("Zoological Transactions," vol. i.).]

Fig 11.



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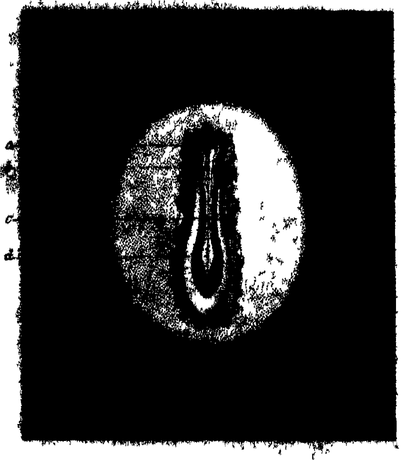

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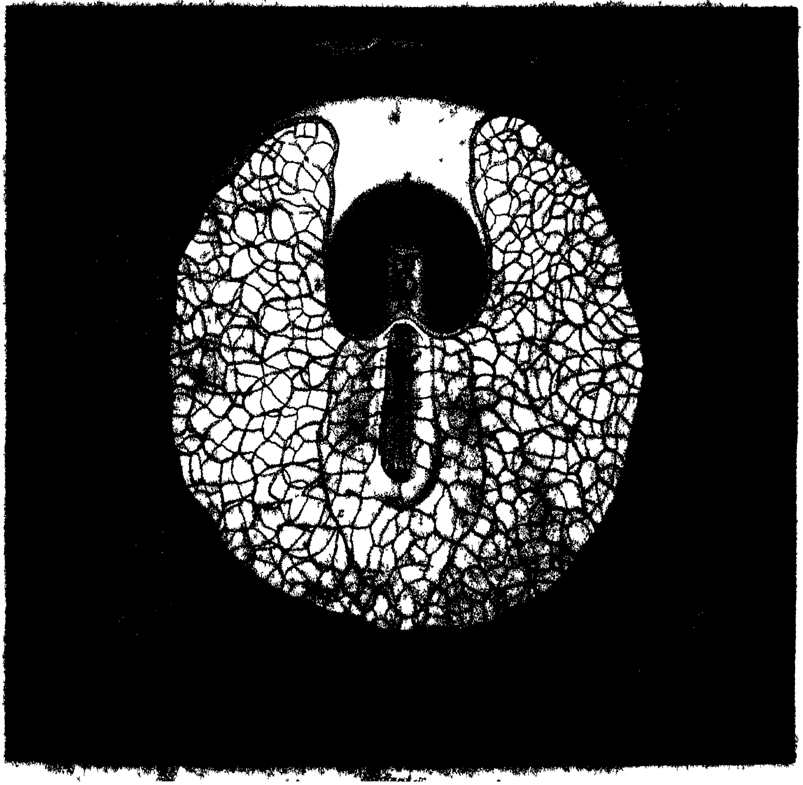

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CHAPTER I.

OF LIFE, AND ITS CONDITIONS.

1. THE term *Life* has been used by different writers, Physiological and Ontological, in a great variety of significations; but these are for the most part capable of reduction to three categories,—Life being regarded either (1) as the *aggregate of the phenomena* exhibited by any Organized being from the commencement to the conclusion of its individual existence, or (2) as the *mode of activity* peculiar to such beings, whereby they are distinguished from inanimate bodies, or (3) as the *special agency* supposed to be inherent in every organism, and to be the efficient cause alike of its first development and of its subsequent maintenance. The first is the sense in which the term is understood by Philosophers of the 'positive' school, who refuse to concern themselves with anything save phenomena that are immediately cognizable by the senses: while the last is the meaning attached to it by such as think that a great deal of trouble is saved by the assumption of a hypothetical entity, whose agency may at once account for everything not to be otherwise explained. To both these definitions it may be objected that they tend to limit inquiry into the essential nature of Vital Action. For by taking the former as our starting-point, we are led to fix our attention too exclusively on the *material conditions* presented in the structure of the Organism, and to ignore the *forces* by which its activity is maintained: just as if, in studying the operations of a Cotton-factory, we were to limit our attention to the mechanism of the carding, spinning, weaving and other machines by whose instrumentality its products are elaborated, and were to neglect, as a condition not directly cognizable by our senses, the Motive Power without which these machines would all be inert. On the other hand, by resting in the assumption of a "Vital Principle" or "Organic Agent" as affording a sufficient account of all that is mysterious in the nature of Life, we really remove it from the domain of scientific inquiry; just as if the visitor to a Cotton-factory were to give up in despair any attempt to acquaint himself with the meaning of the several processes that go on before his eyes, and were to regard it as a sufficient account of the transformation of raw cotton into woven calico, that it takes place by the agency of a "calico-making principle."

2. But if, on the other hand, the Physiologist takes as his stand-point the conception of Life as *a peculiar mode of activity*, he at once finds himself on a pathway of inquiry marked out for him by the antecedent researches of the Physical philosopher. For as, in the study of that great cycle of mutually-related changes which may be designated the Life of the Universe, the Physicist has been led in the first instance to recognise several distinct modes of activity, *e.g.* Mechanical and Chemical, Electrical and

Thermal; and then, prosecuting his analysis under the guidance of that idea of Power which he finds in his own sense of effort, has been brought to refer every effect to a causative Force of some kind, acting through a certain Material instrumentality:—so the Physiologist who makes the living Organism his study, is led in the first place to refer its peculiar phenomena to a set of categories as distinct from the preceding as they are from each other; and thence to distinguish between their *instrumental* and their *dynamical* conditions, the Organic Structure and the Vital Forces which animate it. But further, as the Physicist, in proportion to the elevation of his stand-point and the comprehensiveness of the survey he can thence take of the phenomena of the Inorganic Universe, is enabled to discern, first the mutual relation, and at last the essential unity, of all those Forces whose manifestations appeared so diverse when separately contrasted: so may the Physiologist, in proportion to the insight he gains into the peculiar characteristics of Vital Activity, come in the first instance to recognise the mutual relation of the agencies which underlie its diversified phenomena, next to perceive their fundamental unity as so many expressions of one and the same Vital Force acting through different material instrumentalities, and finally to discern the essential identity of this Force with that which maintains the ceaseless cycle of activity in the Universe at large.*

3. If, now, we inquire what it is that essentially distinguishes Vital from every kind of Physical activity, we find this distinction most characteristically expressed in the fact that a germ endowed with Life developes itself into an Organism of a type resembling that of its parent; that this organism is the subject of incessant changes, which all tend in the first place to the evolution of its typical form, and subsequently to its maintenance in that form, notwithstanding the antagonism of Chemical and Physical agencies which are continually tending to produce its disintegration; but that as its term of existence is prolonged, its conservative power declines so as to become less and less able to resist these disintegrating forces, to which it finally succumbs, leaving the organism to be resolved by their agency into the components from which its materials were originally drawn. The history of a living organism, then, is one of *incessant change*; † and the conditions of this change are to be found partly in the organism itself, and partly in the external influences to which it is subjected.

4. [But the Life of any complex organism, such as that of Man, is the

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* See the Author's Memoir 'On the Mutual Relations of the Vital and Physical Forces,' in the "Philosophical Transactions" for 1850.

† If change be essential to our idea of Life, it may be asked what is the condition of a Seed, which may remain unaltered during a period of many centuries, vegetating at last, when placed in favourable circumstances, as if it had only ripened the year before. We can scarcely call it *alive*, for it is not performing any vital operation. But it is not *dead;* for it has undergone no disintegration, and retains its capacity for living. The most correct designation of such a state (which can only be maintained under a complete seclusion from disintegrating agencies) seems to be *dormant vitality*. Certain Animals may be reduced to it; as the Frog by cold, and the Wheel-animalcule by desiccation. Organisms capable of undergoing such a suspension of activity may be kept in a dormant condition so long as disintegrating agencies are excluded; but the very conditions (as heat in the one case, moisture in the other, and both combined in the case of the seed) whose presence is followed by the renewal of active life if the organism has undergone no injurious change, ensure its speedy decay if it be not able to resume its proper vital activity.

aggregate of the Vital Activity of all its component parts; and we must ascertain the conditions on which the activity of each of these is dependent, before we can rightly comprehend their united action in the Life of the whole. No fact has been more clearly ascertained by modern Physiological research than this,—that as the germ derives from its parent certain independent endowments, in virtue of which it is enabled to develope itself (under appropriate conditions) into an organism which may be composed of a vast number of dissimilar parts, so each of those parts derives from the germ in which it had its origin an independent capacity for development and maintenance, in virtue of which it goes through its own course of vital activity, and by the ultimate cessation of which its own term of existence is limited. Of this mutual independence we have illustrations in the persistence of the 'molecular life' of individual parts long after 'somatic' death (or death of the body as a whole) has taken place;—in the fact that not only may vital activity be sustained in a part completely separated from the body by the maintenance of the circulation of blood through it, but vital endowments which had partially or completely ceased to manifest themselves in consequence of the cessation of the circulation, may be restored by its re-establishment;—and in the occasional reunion of members which have been entirely separated. But notwithstanding the wonderful diversity of structure and of endowments which we meet with in the study of any such complex organism, we encounter a harmonious unity or co-ordination in its entire aggregate of actions, which is yet more wonderful. It is in this harmony or co-ordination, whose tendency is to the conservation of the organism, that the state of Health or Normal Life essentially consists. And the more profound is our investigation of its conditions, the more definite becomes the conclusion to which we are led by the study of them,—that it is fundamentally based on the common origin of all these diversified parts in the same germ, the vital endowments of which, equally diffused throughout the whole fabric in those lowest forms of organization in which every part is but a repetition of every other, are differentiated in the highest amongst a variety of organs or instrumental structures more or less dissimilar, acquiring in virtue of this differentiation a much greater intensity. Thus in the lowest forms of Vegetable life, the primordial germ multiplies itself by duplicative subdivision into an apparently unlimited number of cells, each of them similar to every other, and capable of maintaining its existence independently of them. And in that lowest (Rhizopod) type of Animal life, the knowledge of which is among the most remarkable fruits of modern biological research, "the Physiologist has a case in which those vital operations which he is elsewhere accustomed to see carried on by an elaborate apparatus, are performed without any special instruments whatever; a little particle of apparently homogeneous jelly changing itself into a greater variety of forms than the fabled Proteus, laying hold of its food without members, swallowing it without a mouth, digesting it without a stomach, appropriating its nutritious material without absorbent vessels or a circulating system, moving from place to place without muscles, feeling (if it has any power to do so) without nerves, propagating itself without genital apparatus, and not only this, but in many instances forming shelly coverings of a symmetry and complexity not surpassed by those of any testaceous animals;"* whilst the mere separation of a fragment of this jelly is sufficient to originate a new and independent organism, so that any number of these beings may be produced by the successive detachment of such particles from a single Rhizopod, each of them retaining (so far as we have at present the means of knowing) the characteristic endowments of the stock from which it was an offset. When, on the other hand, we watch the evolution of any of the higher types of Organization, whether Vegetable or Animal, we observe that although in the first instance the primordial cell multiplies itself by duplicative subdivision into an aggregation of cells which are apparently but repetitions of itself and of each other, this homogeneous extension has in each case a definite limit, speedily giving place to a structural differentiation which becomes more and more decided with the progress of development; until, in that most heterogeneous of all types—the Human Organism—no two parts are precisely identical, except those which correspond to each other on the opposite sides of the body. With this structural differentiation is associated a corresponding differentiation of function; for whilst in the Life of the most highly-developed and complex organism we witness no act which is not foreshadowed, however vaguely, in that of the lowest and simplest, yet we observe in it that same "division of labour" which constitutes the essential characteristic of the highest grade of Civilization. For in what may be termed the elementary form of Human Society, in which every individual relies upon himself alone for the supply of all his wants, no greater result can be attained by the aggregate action of the entire community than its mere maintenance; but as each individual selects a special mode of activity for himself, and aims at improvement in that speciality, he finds himself attaining a higher and yet higher degree of aptitude for it; and this specialization tends to increase as opportunities arise for new modes of activity, until that complex fabric is evolved which constitutes the most developed form of the Social State, wherein every individual finds the work—mental or bodily—for which he is best fitted, and in which he may reach the highest attainable perfection; while the mutual dependence of the whole (which is the necessary result of this specialization of parts) is such that every individual works for the benefit of all his fellows, as well as for his own. As it is only in such a state of Society that the greatest triumphs of Human ability become possible, so it is only in the most differentiated types of Organization that Vital Activity can present its highest manifestations. In the one case as in the other does the result depend upon a process of gradual *development*, in which, under the influence of agencies whose nature constitutes a proper object of scientific inquiry, that *most general* form in which the fabric—whether Corporeal or Social—originates, evolves itself into that *most special* in which its development culminates. And hence we are distinctly justified in the conclusion, that the special endowments of the several components of the organism, however dissimilar to each other, are nothing else than differentiated and proportionately intensified expressions of those which are common to every part of the originally homogeneous fabric;—a conclusion which derives a remarkable confirmation from the

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*** See the Author's "Introduction to the Study of the Foraminifera," published by the Ray Society, 1862, Preface, p. vii.**

indication afforded by the phenomena of 'Metastasis of Secretion' (CHAP. IX.), that the general structure, even in the most highly-specialized organism, retains somewhat of its primitive community of function.

5. Thus, then, we may take that mode of Vital Activity which manifests itself in the evolution of the germ into the complete organism repeating the type of its parent, and the subsequent maintenance of that organism in its integrity,—in both cases at the expense of materials derived from external sources,—as the most universal and most fundamental characteristic of Life; and we have now to consider the nature and source of the Force or Power by which that evolution is brought about. The prevalent opinion has until lately been, that this power is inherent in the germ; which has been supposed to derive from its parent not merely its material substance, but a *nisus formativus*, *bildungstrieb*, or *germ-force*, in virtue of which it builds itself up into the likeness of its parent, and maintains itself in that likeness until the force is exhausted, at the same time imparting a fraction of it to each of its progeny. In this mode of viewing the subject, all the organizing force required to build up an Oak or a Palm, an Elephant or a Whale, must be concentrated in a minute particle, only discernible by microscopic aid; and the aggregate of all the germ-forces appertaining to the descendants, however numerous, of a common parentage, must have existed in their original progenitors. Thus, in the case of the successive viviparous broods of *Aphides*, a germ-force capable of organizing a mass of living structure, which would amount (it has been calculated)* in the tenth brood to the bulk of 500 millions of stout men, must have been shut up in the single individual, weighing perhaps the 1-1000th of a grain, from which the first brood was evolved. And in like manner, the germ-force which has organized the bodies of all the individual men that have lived from Adam to the present day, must have been concentrated in the body of their common ancestor. A more complete *reductio ad absurdum* can scarcely be brought against any hypothesis; and we may consider it proved that, in some way or other, fresh organizing force is constantly being supplied *from without* during the whole period of the exercise of its activity. When we carefully look into the question, we find that what the *germ* really supplies is not the force, but the *directive agency;* thus rather resembling the control exercised by the superintendent builder who is charged with the working-out the design of the architect, than the bodily force of the workmen who labour under his guidance in the construction of the fabric. The actual constructive force, as we learn from an extensive survey of the phenomena of life, is supplied by Heat; the influence of which upon the rate of growth and development, both animal and vegetable, is so marked as to have universally attracted the attention of Physiologists; who, however, have for the most part only recognised in it a *vital stimulus* that calls forth the latent power of the germ, instead of looking upon it as itself furnishing the power that does the work. It has been from the narrow limitation of the area over which physiological research has been commonly prosecuted, that the intimacy of this relationship between Heat and the Organizing force has not sooner become apparent. Whilst the vital phenomena of Warm-blooded

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* See Prof. Huxley on the 'Agamic Reproduction of Aphis,' in "Linn. Trans.," vol. xxii., p. 215.

Animals, which possess within themselves the means of maintaining a constant temperature, were made the sole, or at any rate the chief objects of study, it was not likely that the inquirer would recognise the full influence of external heat in accelerating, or of cold in retarding, their functional activity. It is only when the survey is extended to Cold-blooded Animals, and to Plants, that the immediate and direct relation between Heat and Vital Activity, as manifested in the rate of growth and development, or of other changes peculiar to the living body, is unmistakeably manifested. To some of those phenomena which afford the best illustrations of the mode in which Heat acts upon the living organism, attention will now be directed.

6. The agency of Heat as the 'efficient cause' or 'motive power' to which the phenomena of growth and development are to be referred, is peculiarly well seen in the process of Germination. The seed consists of an embryo which has already advanced to a certain stage of development, and of a store of nutriment laid up as the material for its further evolution; and in the fact that this evolution is carried on at the expense of organic compounds already prepared by extrinsic agency, until (the store of these being exhausted) the young plant is sufficiently far advanced in its development to be able to elaborate them for itself, the condition of the germinating embryo resembles that of an Animal. Now the seed, as already pointed out, may remain (under favourable circumstances) in a state of absolute inaction during an unlimited period. If secluded from the free access of air and moisture, and kept at a low temperature, it is removed from all influences that would on the one hand occasion its disintegration, or on the other would call it into active life. But when again exposed to air and moisture, and subjected to a higher temperature, it either germinates or decays, according as the embryo it contains has or has not preserved its vital endowments,—a question which only experiment can resolve. The process of germination is by no means a simple one. The nutriment stored up in the seed is in great part in the condition of insoluble starch; and this must be brought into a soluble form before it can be appropriated by the embryo. The metamorphosis is effected by the agency of a ferment termed *diastase;* which is laid up in the immediate neighbourhood of the embryo, and which, when brought to act on starch, converts it in the first instance into soluble dextrine, and then (if its action be continued) into sugar. The dextrine and sugar, combined with the albuminous and oily compounds also stored-up in the seed, form the 'protoplasm' which is the substance immediately supplied to the young plant as the material of its tissues; and the conversion of this protoplasm into various forms of organized tissue, which become more and more differentiated as development advances, is obviously referable to the vital activity of the germ. Now it can be very easily shown experimentally that the *rate of growth* in the germinating embryo is so closely related (within certain limits) to the amount of Heat supplied, as to place its dependence on that agency beyond reasonable question; so that we seem fully entitled to say that Heat, acting through the germ becomes the constructive force or power by which the Vegetable fabric is built up.* But there appears to be another source of that power in th

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* The effect of Heat is doubtless manifested very differently by different seeds; suc variations being partly *specific,* partly *individual.* But these are no greater than w

seed itself. In the conversion of the insoluble starch of the seed into sugar, and probably also in a further metamorphosis of a part of that sugar, a large quantity of carbon is eliminated from the seed by combining with the oxygen of the air so as to form carbonic acid; this combination is necessarily attended with a disengagement of heat, which becomes very sensible when (as in malting) a large number of germinating seeds are aggregated together; and it cannot but be regarded as probable that the heat thus evolved within the seed concurs with that derived from without, in supplying to the germ the force that promotes its evolution.

7. The condition of the Plant which has attained a more advanced stage of its development, differs from that of the germinating embryo essentially in this particular, that the organic compounds which it requires as the materials of the extension of the fabric are formed by itself, instead of being supplied to it from without. The tissues of the green surfaces of the leaves and stems, when acted on by light, have the peculiar power of generating, at the expense of carbonic acid, water, and ammonia, various ternary and quaternary organic compounds, such as chlorophyll, starch, oil, and albumen; and of the compounds thus generated, a part ~~are~~ appropriated by the constructive force of the Plant (derived from the heat with which it is supplied) to the formation of new tissues; whilst a part ~~are~~ stored up in the cavities of those tissues, where they ultimately serve either for the evolution of parts subsequently developed, or for the nutrition of animals which employ them as food. Of the source of those peculiar affinities by which the components of the Starch, Albumen, &c. are brought together, we have no right to speak confidently; but looking to the fact that these compounds are not produced in any case by the direct union of their elements, and that a decomposition of binary compounds seems to be a necessary antecedent of their formation, it is scarcely improbable that, as suggested by Prof. Le Conte,* that source is to be found in the chemical forces set free in the preliminary act of decomposition, in which the elements would be liberated in that 'nascent condition' which is well known to be one of peculiar energy. The influence of Light, then, upon the Vegetable organism appears to be essentially exerted in bringing about what may be considered a higher mode of chemical combination between oxygen, hydrogen, and carbon, with the addition of nitrogen in certain cases; and there is no evidence that it extends beyond this. That the appropriation of the materials thus prepared, and their conversion into organized tissue in the operations of growth and development, are dependent on the agency of Heat, is just as evident in the stage of maturity as in that of germination. And there is reason to believe, further, that an additional source of organizing force is to be found in the retrograde metamorphosis of organic compounds that goes on during the whole life of the plant; of which metamorphosis

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see in the Inorganic world; the increment of temperature and the augmentation of bulk exhibited by different substances when subjected to the same absolute measure of heat, being as diverse as the substances themselves. The whole process of 'malting,' it may be remarked, is based on the average regularity with which the seeds of a particular species may be at any time forced to a definite rate of germination by a definite increment of temperature.

* See his very suggestive Memoir 'On the Correlation of Physical, Chemical, and Vital Force,' in the "Philosophical Magazine" for 1860, vol. xix., Ser. IV., p. 137.

the expression is furnished by the production of carbonic acid. This is peculiarly remarkable in the case of the *Fungi*, which, being incapable of forming new compounds under the influence of light, are entirely supported by the organic matters they absorb, and in this respect correspond on the one hand with the germinating embryo, and on the other with Animals. Such a decomposition of a portion of the absorbed material is the only conceivable source of the large quantity of carbonic acid they are constantly giving out; and it would not seem unlikely that the force supplied by this retrograde metamorphosis of the superfluous components of their food, which fall down (so to speak) from the elevated plane of 'proximate principles' to the lower level of comparatively simple binary compounds, constitutes the power by which another portion is raised to the rank of living tissue; thus accounting in some degree for the very rapid growth for which this tribe of Plants is so remarkable. This exhalation of carbonic acid, however, is not peculiar to Fungi and germinating embryos; for it takes place during the whole life of Flowering Plants, both by day and by night, in sunshine and in shade, and from their green as well as from their dark surfaces. And it is not improbable that, as in the case of the Fungi, its source lies partly in the organic matters absorbed; recent investigations* having rendered it probable that Plants really take up and assimilate soluble *humus*, which, being a more highly carbonized substance than starch, dextrine, or cellulose, can only be converted into compounds of the latter kind by parting with some of its carbon; but it may also take place at the expense of compounds previously generated by the plant itself, and stored up in its tissues, of which we seem to have an example in the unusual production of carbonic acid which takes place at the period of flowering, especially in such plants as have a fleshy disk or receptacle containing a large quantity of starch; and thus, it may be surmised, an extra supply of force is provided for the maturation of those generative products, whose preparation seems to be the highest expression of the vital power of the Vegetable organism.

8. The entire aggregate of organic compounds contained in the Vegetable tissues, then, may be considered as the expression not merely of a certain amount of the *material elements* oxygen, hydrogen, carbon, and nitrogen derived (directly or indirectly) from the water, carbonic acid, and ammonia of the atmosphere, but also of a certain amount of *force* which has been exerted, in raising these from the lower plane of simple binary compounds to the higher level of complex 'proximate principles;' whilst the portion of these actually converted into organized tissue may be considered as the expression of a further measure of force, which, acting under the directive agency of the germ, has served to build up the fabric in its characteristic type. This *constructive* action goes on during the whole Life of the Plant, which essentially manifests itself either in the extension of the original fabric (to which in many instances there seems no determinate limit), or in the production of the germs of new and independent organisms.—It is interesting to remark that the development of the more permanent parts involves the successional decay and renewal of parts whose existence is temporary. The 'fall of the leaf' is the effect,

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* See the Memoir of M. Risler, 'On the Absorption of Humus,' in the "Bibliothèque Universelle," N.S., 1858, tom. i. p. 305.

not the cause, of the cessation of that peculiar functional activity of its tissues, which consists in the elaboration of the nutritive material required for the production of wood. And it would seem as if the duration of their existence stands in an inverse ratio to the energy of their action; the leaves of "evergreens," which are not cast off until the appearance of a new succession, effecting their functional changes at a much less rapid rate than do those of "deciduous" trees, whose term of life is far more brief.—Thus the final cause or purpose of the whole Vital Activity of the Plant, so far as the *individual* is concerned, is to produce an indefinite extension of the dense, woody, almost inert, but permanent portions of the fabric, by the successional development, decay, and renewal of the soft, active, and transitory cellular parenchyma; and, according to the principles already stated, the descent of a portion of the materials of the latter to the condition of binary compounds, which is manifested in the largely increased exhalation of carbonic acid that takes place from the leaves in the later part of the season, comes to the aid of external Heat in supplying the force by which another portion of those materials is raised to the condition of organized tissue.—The vital activity of the Plant, however, is further manifested in the provision made for the propagation of its race by the production of the germs of new individuals; and here, again, we observe that whilst a higher temperature is usually required for the development of the flower and the maturation of the seed than that which suffices to sustain the ordinary processes of vegetation, a special provision appears to be made in some instances for the evolution of force in the sexual apparatus itself, by the retrograde metamorphosis of a portion of the organic compounds prepared by the previous nutritive operations.* This seems the nearest approach presented in the Vegetable organism, to what we shall find to be an ordinary mode of activity in the Animal. That the performance of the generative act involves an extraordinary expenditure of vital force, appears from this remarkable fact, that blossoms which wither and die as soon as the ovules have been fertilized, may be kept fresh for a long period if fertilization be prevented.

9. We are now prepared to inquire into the manifestations of Vital Activity in the Animal, and into the sources of the power by which the various forms of that activity are sustained. The first of these manifestations is, as in the plant, the building-up of the organism by the appropriation of material supplied from external sources under the directive agency of the germ. The ovum of the Animal, like the seed of the Plant, contains a store of appropriate nutriment previously elaborated by the parent; and this store suffices for the development of the embryo, up to the period at which it can obtain and digest alimentary materials for itself. That period occurs in the different tribes of animals at very dissimilar stages of the entire developmental process. In many of the lower classes, the embryo comes forth from the egg, and commences its independent existence, in a condition which, as compared with the adult form, would be as if a Human embryo were to be thrown upon the world to obtain its own subsistence only a few weeks after conception; and its whole subsequent growth and development take place at the expense of the nutriment which it ingests for itself. We have examples of this in the

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* See "Principles of Comparative Physiology," 4th Edit. § 274.

class of Insects, many of which come forth from the egg in the state of extremely simple and minute worms, having scarcely any power of movement, but an extraordinary voracity. The eggs having been deposited in situations fitted to afford an ample supply of appropriate nutriment (those of the flesh-fly, for example, being laid in carcases, and those of the cabbage-butterfly upon cabbage-leaves), each larva on its emersion is as well provided with alimentary material as if it had been furnished with a large supplemental yolk of its own; and by availing itself of this, it speedily grows to many hundred or even many thousand times its original size, without making any considerable advance in development. But having thus laid up in its tissues a large additional store of material, it passes into a state which, so far as the external manifestations of life are concerned, is one of torpor, but which is really one of great developmental activity; for it is during the *pupa* state that those new parts are evolved, which are characteristic of the perfect Insect, and of which scarcely a trace was discoverable in the larva; so that the assumption of this state may be likened in many respects to a re-entrance of the larva into the ovum. On its termination, the Imago or perfect Insect comes forth complete in all its parts, and soon manifests the locomotive and sensorial powers by which it is specially distinguished, and of which the extraordinary predominance seems to justify our regarding Insects as the types of purely *Animal* life. There are some Insects whose Imago-life has but a very short duration, the performance of the generative act being apparently the only object of this stage of their existence: and such for the most part take no food whatever after their final emersion, their vital activity being maintained, for the short period it endures, by the material assimilated during their larva state.* But those whose period of activity is prolonged, and upon whose energy there are extraordinary demands, are scarcely less voracious in their imago than in their larva-condition; the food they consume not being applied to the *increase* of their bodies, which grow very little after the assumption of the imago-state, but chiefly to their *maintenance*,—no inconsiderable portion of it, however, being appropriated in the female to the production of ova, the entire mass of which deposited by a single individual is sometimes enormous. That the performance of the generative act involves not merely a consumption of material, but a special expenditure of force, appears from a fact to be presently stated, corresponding to that already noticed (§ 8) in regard to Plants.

10. Now if we look for the source of the various kinds of force,—which may be distinguished as constructive, sensori-motor, and generative,—that are manifested in the different stages of the life of an Insect, we find them to lie, on the one hand, in the Heat with which the organism is supplied from external sources, and, on the other, in the Food provided for it. The agency of heat, as the moving power of the constructive operations, is even more distinctly shown in the development of the larva within the egg, and in the development of the imago within its pupa-case, than it is in the germinating seed; the rate of each of these processes being

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* It is not a little curious that in the tribe of *Rotifera*, or Wheel-animalcules, all the males yet discovered are entirely *asplanchnic;* not only the whole of their development within the egg, but the whole of their active life after their emersion from it being carried-on at the expense of the store of yolk provided by the parent.

strictly regulated by the temperature to which the organism is subjected. Thus ova which are ordinarily not hatched until the leaves suitable for the food of their larva have been put forth, may be made, by artificial heat, to produce a brood in the winter; whilst, on the other hand, if they be kept at a low temperature, their hatching may be retarded almost indefinitely without the destruction of their vitality. The same is true of the pupa-state; and it is remarkable that during the latter part of that state, in which the developmental process goes on with extraordinary rapidity, there is in certain Insects a special provision for an elevation of the temperature of the embryo by a process resembling incubation. Whether, in addition to the heat imparted from without, there is any addition of force developed within (as in the germinating seed) by the return of a part of the organic constituents of the food to the condition of binary compounds, cannot at present be stated with confidence: the probability is, however, that such a retrograde metamorphosis does take place, adequate evidence of its occurrence during the incubation of the Bird's egg being afforded by the liberation of carbonic acid which is there found to be an essential condition of the developmental process. During the larva-state there is very little power of maintaining an independent temperature, so that the sustenance of Vital Activity is still mainly due to the heat supplied from without.—But in the active state of the perfect Insect there is a *production of heat* quite comparable to that of warm-blooded animals; and this is effected by the retrograde metamorphosis of certain organic constituents of the food, of which we find the expression in the exhalation of carbonic acid and water. Thus the food of Animals becomes an internal source of heat, which may render them independent of external temperature.—Further, a like retrograde metamorphosis of certain constituents of the food is the source of that *sensori-motor power* which is the peculiar characteristic of the Animal organism; for on the one hand the demand for food, on the other the amount of metamorphosis indicated by the quantity of carbonic acid exhaled, bear a very close relation to the quantity of that power which is put forth. This relation is peculiarly manifest in Insects, since their conditions of activity and repose present a greater contrast in their respective rates of metamorphosis than do those of any other animals.—Of the exercise of *generative* force we have no similar measure; but that it is only a special modification of ordinary vital activity appears from this circumstance, that the life of those Insects which ordinarily die very soon after sexual congress and the deposition of the ova, may be considerably prolonged if the sexes be kept apart so that congress cannot take place. Moreover, it has been shown by recent inquiries into the Agamic reproduction of Insects and other animals, that the process of Generation differs far less from those Reproductive acts which must be referred to the category of the ordinary Nutritive processes, than had been previously supposed.

11. Thus, then, we find that in the Animal organism the demand for food has reference not merely to its use as a *material* for the construction of the fabric; food serves also as a generator of *force;* and this force may be of various kinds,—Heat and Motor-power being the principal but by no means the only modes under which it manifests itself. We shall now inquire what there is peculiar in the sources of the Vital Force which animates the organisms of the higher animals at different stages of Life.

12. That the Developmental force which occasions the evolution of the germ in the higher Vertebrata is really supplied by the Heat to which the ovum is subjected, may be regarded as a fact established beyond all question. In the Frog and other Amphibia, which have no special means of imparting a high temperature to their eggs, the rate of development (which in the early stages can be readily determined with great exactness) is entirely governed by the degree of warmth to which the ovum is subjected. But in Serpents there is a peculiar provision for supplying heat; the female performing a kind of incubation upon her eggs, and generating in her own body a temperature much above that of the surrounding air.* In Birds, the developmental process can only be maintained by the steady application of external warmth, and this to a degree much higher than that which is needed in the case of cold-blooded animals; and we may notice two results of this application as very significant of the dynamical relation between Heat and Developmental Force,—first, that the period required for the evolution of the germ into the mature embryo is nearly constant, each species having a definite period of incubation,—and second, that the grade of development attained by the embryo before its emersion is relatively much higher than it is in cold-blooded vertebrata generally; the only instances in which anything like the same stage is attained without a special incubation being those in which (as in the Turtle and Crocodile) the eggs are hatched under the influence of a high external temperature. This higher development is attained at the expense of a much greater consumption of nutrient material; the store laid up in the 'food yolk' and 'albumen' of the Bird's egg being many times greater in proportion to the size of the animal which laid it, than that contained in the whole egg of a Frog or a Fish. There is evidence in that liberation of carbonic acid which has been ascertained to go on in the egg (as in the germinating seed) during the whole of the developmental process, that the return of a portion of the organic substances provided for the sustenance of the embryo, to the condition of simple binary compounds, is an essential condition of the process; and since it can scarcely be supposed that the object of this metamorphosis can be to furnish *heat* (an ample supply of that force being afforded by the body of the parent), it seems not unlikely that its purpose is to supply a force that concurs with the heat received from without in maintaining the process of organization.—The development of the embryo within the body, in the Mammalia, imparts to it a steady temperature equivalent to that of the parent itself; and in all save the *implacental* Orders of this class, that development is carried still further than in Birds, the new-born Mammal being yet more complete in all its parts, and its size bearing a larger proportion to that of its parent, than even in Birds. It is doubtless owing in great part to the constancy of the temperature to which the embryo is subjected, that its rate of development (as shown by the fixed term of utero-gestation) is so uniform. The supply of organizable material here afforded by the ovum itself is very small, and suffices only for the very

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* In the Viper the eggs are usually retained within the oviduct until they are hatched. In the Python, which recently went through the process of incubation in the Zoological Gardens, the eggs were imbedded in the coils of the body; the temperature to which they were subjected (as ascertained by a thermometer placed in the midst of them) averaging 90° F., whilst that of the cage averaged 60° F.

earliest stage of the constructive process; but a special provision is very soon made for the nutrition of the embryo by materials directly supplied by the parent; and the imbibition of these takes the place, during the whole remainder of fœtal life, of the appropriation of the materials supplied in the Bird's egg by the 'food yolk' and 'albumen.' To what extent a retrograde metamorphosis of nutrient material takes place in the fœtal Mammal, we have no precise means of determining; since the products of that metamorphosis are probably for the most part returned (through the placental circulation) to the blood of the mother, and got rid of through her excretory apparatus. But sufficient evidence of such a metamorphosis is afforded by the presence of urea in the amniotic fluid and of biliary matter in the intestines, to make it probable that it takes place not less actively (to say the least) in the fœtal Mammal than it does in the Chick *in ovo.* Indeed it is impossible to conceive of the growth of any of the higher organisms,—which not merely consists in the formation of new parts, but also involves a vast amount of interstitial change,—without perceiving that in the remodelling which is incessantly going on, the parts first formed must be removed to make way for those which have to take their place. And such removal can scarcely be accomplished without a retrograde metamorphosis, which, as in the numerous cases already referred-to, may be considered with great probability as setting free constructive force to be applied in the production of new tissue.

13. If, now, we pass-on from the intra-uterine life of the Mammalian organism to that period of its existence which intervenes between birth and maturity, we see that a temporary provision is made in the acts of lactation and nursing for affording both food and warmth to the young creature, which is at first incapable of adequately providing itself with aliment, or of resisting external cold without fostering aid. And we notice that the offspring of Man remains longer dependent upon parental care than that of any other Mammal; in accordance with the higher grade of development to be ultimately attained. But when the period of infancy has passed, the child that is adequately supplied with food, and is protected by the clothing which makes up for the deficiency of other tegumentary covering, ought to be able to maintain its own heat, save in an extremely depressed temperature; and this it does by the metamorphosis of organic substances, partly derived from its own fabric, and partly supplied directly by the food, into binary compounds. During the whole period of growth and development, we find the producing power at its highest point; the circulation of blood being more rapid, and the amount of carbonic acid generated and thrown off being much greater in proportion to the bulk of the body, than at any subsequent period of life. We find, too, in the large amount of other excretions, the evidence of a rapid metamorphosis of tissue; and it can hardly be questioned (if our general doctrines be well founded) that the constructive force which operates in the completion of the fabric will be derived in part from the heat so largely generated by chemical change, and in part from the descent which a portion of the fabric itself is continually making from the higher plane of organized tissue to the lower plane of dead matter. This high measure of vital activity can only be sustained by an ample supply of Food; which thus supplies both *material* for the construction of the

organism, and the *force* by whose agency that construction is accomplished. How completely dependent the constructive process still is upon Heat, is shown by the phenomena of reparation in cold-blooded animals; since not only can the rate at which they take place be experimentally shown to bear a direct relation to the temperature to which these animals are subjected, but it has been ascertained that any extraordinary act of reparation (such as the reproduction of a limb in the Salamander) will only be performed under the influence of a temperature much higher than that required for the maintenance of the ordinary vital activity.—After the maturity of the organism has been attained, there is no longer any call for a larger measure of constructive force than is required for the *maintenance* of its integrity; and if there were no other source of retrograde metamorphosis than that which is inherent in the peculiar composition of the tissues, the demand for food would be reduced to very little more than would suffice by its ultimate conversion into water and carbonic acid to keep up the temperature of the body. But the conditions of Animal existence involve a constant expenditure of *Motor* force through the instrumentality of the Nervo-muscular apparatus, as well as a liberation of Heat; and the exercise of the purely *Psychical* powers through the instrumentality of the Brain constitutes a further expenditure of force, even when no bodily exertion is made as its result.—We have now to consider the conditions under which these forces are developed, and the sources from which they are derived.

14. The doctrine at present commonly received among Physiologists upon these points may be stated as follows:—The functional activity of the Nervous and Muscular apparatuses involves, as its necessary condition, the disintegration of their tissues; the components of which, uniting with the oxygen of the blood, enter into new and simpler combinations, which are ultimately eliminated from the body by the excretory operations.* In such a retrograde metamorphosis of tissue, we have two sources of the liberation of force;—first, its descent from the condition of living to that of dead matter, involving a liberation of that force which was originally concerned in its organization;—and second, the further descent of its

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* To this doctrine a decided approach was made by Liebig in his Animal Chemistry (1842); since he there distinctly promulgated what had already been more vaguely affirmed by various Physiologists, that every production of motion by an Animal involves a proportional disintegration of muscular substance. But he seems to have regarded the motor force produced as the expression of the vital force by which the tissue was previously animated; and to have looked upon its disintegration by oxygenation as simply a consequence of its death. The doctrine of the "Correlation of Forces" being at that time undeveloped, he was not prepared to recognise a source of Motor power in the ulterior chemical changes which the substance of the muscle undergoes; but seems to have regarded them as only concerned in the production of Heat. The earliest distinct expression of the current doctrine is to be found in the very remarkable treatise of Dr. Mayer ("Die organische Bewegung in ihren Zusammenhange mit dem Stoffwechsel," *Heilbronn*, 1845), in which he worked-out from the two fundamental axioms, "*Ex nihilo nil fit*," and "*Nil fit ad nihilum*," the whole system of doctrine which has since come to be known as that of the "Correlation of Forces," and the "Conservation of Force," in its application alike to Physics and Chemistry and to Physiology. Prof. Grove was simultaneously engaged in the development of the doctrine of the "Correlation of the Physical Forces;" and without any knowledge of Dr. Mayer's previous labours, the Author of this Treatise developed the doctrine in the form stated in the text, in his Memoir 'On the Mutual Relations of the Vital and Physical Forces,' published in the "Philosophical Transactions" for 1850.

complex organic components to the lower plane of simple binary compounds. If we trace back these forces to their proximate source, we find both of them in the *food* at the expense of which the Animal organism is constructed; for besides supplying the material of the tissues, a portion of that food (as already shown) becomes the source, in its retrograde metamorphosis, of the production of the Heat which supplies the constructive power, whilst another portion may afford, by a like descent, a yet more direct supply of organizing force. And thus we find in the action of Solar Light and Heat upon Plants—whereby they are enabled to not merely extend themselves almost without limit, but also to accumulate in their substance a store of Organic Compounds for the consumption of Animals,—the ultimate source, not merely of the materials which Animals require for their nutrition, but also of the forces of various kinds which they exert.

15. But recent investigations have rendered it doubtful whether the doctrine that every exertion of the functional power of the nervo-muscular apparatus involves the disintegration of a certain equivalent amount of tissue, really expresses the whole truth. It has been maintained, on the basis of carefully conducted experiments, in the first place, that the amount of work done by an animal may be greater than can be accounted for by the ultimate metamorphosis of the azotized constituents of its food, their mechanical equivalent being estimated by the heat producible by the combustion of the carbon and oxygen which they contain;* and secondly, that whilst there is not a constant relation (as affirmed by Liebig) between the amount of motor force produced and the amount of disintegration of muscular tissue represented by the appearance of urea in the urine, such a constant relation does exist between the development of motor force and the increase of carbonic acid in the expired air as shows that between these two phenomena there is a most intimate connection.† And the concurrence of these independent indications

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* This view has been expressed to the Author by two very high authorities, Prof. Helmholtz and Prof. William Thomson, independently of each other, as an almost necessary inference from the data furnished by the experiments of Dr. Joule. Even admitting these data (as to which he learns from Dr. Joule that he has now some doubt, arising from the incompleteness of the analyses of the food consumed by the Horse which was the subject of the experiment), the Author is by no means satisfied that they justify the inference founded on them; for it seems to him a pure assumption to affirm that the force evolved by the ultimate metamorphosis of *azotized* compounds is to be measured only by the combustive equivalent of the *carbon* and *hydrogen* they contain. There is abundant evidence in the phenomena of Vegetable life on the one hand, that the production of gluten and other albuminous compounds is the result of a more powerful action of Heat and Light, than that which is expressed by the production of starch and oil; whilst, on the other hand, chemists are familiar with various phenomena attending the retrograde metamorphosis of azotized compounds, which seem to mark their special potency. So, again, it is quite conceivable that in the construction of Muscular tissue an amount of Organizing force may be as it were locked up (like the power employed in winding-up a watch), to be restored in the form of mechanical force (as in the unbending of the spring), when, in the disintegration of the muscle and the ultimate metamorphosis of its substance, its constituent particles make the entire descent from the highest plane (that of organized tissue) to the lowest (that of simple binary compounds).—But although he cannot regard the doctrine of his distinguished friends as sustainable on the basis on which they have erected it, he thinks it supported by many other considerations leading to the general conclusion (*c*) expressed in the ensuing paragraph of the text.

† On these last points reference is especially made to the experiments of Dr. Edward Smith, the most important results of which will be cited hereafter.

seems to justify the inference that *motor force* may be developed, like Heat, by the metamorphosis of constituents of food which are not converted into living tissue,—an inference which so fully harmonizes with the doctrine of the direct convertibility of these two forces now established as one of the surest results of Physical investigation, as to have in itself no inherent improbability. Of the conditions which determine the generation of motor force, on the one hand from the disintegration of muscular tissue, on the other from the metamorphosis of the components of the food, nothing definite can at present be stated; but we seem to have a typical example of the former in the parturient action of the uterus, whose muscular substance appears to have been built up for this one effort, and forthwith undergoes a rapid retrograde metamorphosis; whilst it can scarcely be regarded as improbable that the constant activity of the heart and of the respiratory muscles, which gives them no opportunity of renovation by rest, is sustained not so much by the continual renewal of their substance (of which renewal there is no histological evidence whatever) as by a metamorphosis of matters external to themselves, supplying a force which is exerted through their instrumentality.

16. To sum up:—The Life of Man essentially consists in the manifestation of Forces of various kinds, of which his organism is the instrument; and these Forces are developed by the retrograde metamorphosis of the Organic Compounds generated by the instrumentality of the Plant, whereby they ultimately return to the simple binary forms (water, carbonic acid, and ammonia) which serve as the food of plants. Of these Organic Compounds, one portion (*a*) is converted into the substance of the living body, by a constructive force which (in so far as it is not supplied by the direct agency of external heat) is developed by the retrograde metamorphosis of another portion (*b*) of the food. And whilst the ultimate descent of the first-named portion (*a*) to the simple condition from which it was originally drawn, becomes one source of the peculiarly Animal powers—the *psychical* and the *motor*—exerted by the organism, another source of these may be found in a like metamorphosis of a further portion (*c*) of the food which has never been converted into living tissue. The generative force, as in the Plant, is evidently an expression of the ordinary constructive force; and there seems reason, moreover, for regarding it as a very high expression, its too rapid expenditure producing a peculiarly depressing effect upon the vital power of the organism, which tends to its dissolution.—But whilst we find the ultimate source of the whole vital power of the organism in the supplies of Food and of Heat which it derives from external sources, it must never be forgotten that its capacity to avail itself of those supplies depends upon its own original constitution; and that as the form into which the germ developes itself depends upon its own *specific* endowments, so the particular modification of that form presented by each individual must depend (all external conditions being the same) upon its own *individual* endowments—the differences between these being at present only vaguely referable to antecedent conditions of the parental organism.

CHAPTER II.

DISTINCTIVE CHARACTERISTICS OF MAN.

17. In entering upon the study of that aggregation of phenomena which constitutes the Life of Man, it seems appropriate in the first instance to consider his relations to other types of Animal organization; and to examine what there is in his corporeal and psychical characters, which most distinctly differentiates him from the beings he most nearly resembles. All Zoologists are agreed that his place is at the head of the Mammalian class of the Vertebrate sub-kingdom; and that as regards both the general plan of conformation and the details of anatomical structure, there is a very close approximation between the genus *Homo* and the semi-erect tail-less Apes belonging to the genera *Troglodytes* and *Pithecus*. But there is a considerable difference of opinion as to the mode in which this relationship should be expressed. By Linnæus, the Apes and Man were included with Lemurs and Bats in one and the same Order PRIMATES; and in this non-separation of Man from the Apes, he has been followed by several modern Zoologists of great eminence. On the other hand Blumenbach, who in this was followed by Cuvier, maintained that the distinctive characters of the genus *Homo* are sufficient to entitle Man to rank as the type of a separate Order, to which he gave the name of BIMANA, considering it to be specially distinguished by the possession of two hands from the QUADRUMANA, which possess four nearly similar hand-like extremities. And Prof. Owen has recently gone a step further, by raising *Homo* into a sub-class ARCHENCEPHALA, on the ground that his "psychological powers, in association with his extraordinarily developed brain, entitle the group which he represents to equivalent rank with the other primary divisions of the class Mammalia, founded on cerebral characters."* Although the discussion of questions of systematic arrangement is the proper business of the Zoologist, yet the inquiry into the exact nature and amount of the differences between *Man* and the (so-called) *Quadrumana* falls legitimately within the province of the Physiologist, and may therefore be appropriately dealt with in this place. In the pursuit of this inquiry, it is most important to distinguish between those structural peculiarities of which alone the Anatomist can take cognizance, and those psychical manifestations of which the sources are altogether beyond his ken; for these two orders of facts cannot be legitimately brought into the same category, and any attempts to blend them can lead to nothing but confusion. It is the province of the Comparative Anatomist to deal with Man's corporeal organism, as if he knew nothing more than the facts brought under his observation in the dissecting-room; scrutinizing every peculiarity in its structure in exactly the same spirit, and valuing it according to exactly the same measure, that he would bring to the investigation of the peculiarities of some newly-discovered type, known to him only by

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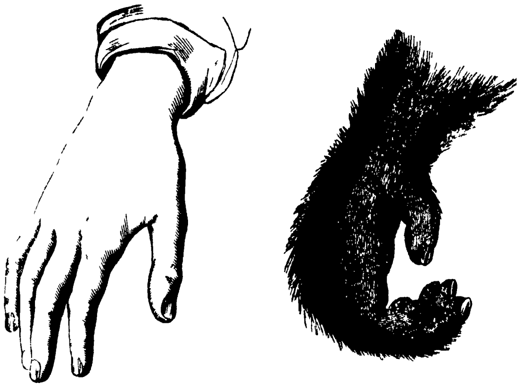
* 'On the Characters and Classification of the Mammalia,' in "Journal of the Proceedings of the Linnæan Society," vol. ii., 1857, p. 33.

dead specimens. And although he might safely assign to the genus *Homo* a structural capacity for the erect posture,—a speciality in the conformation of the anterior and posterior extremities, imparting to the former a peculiar power of varied and minute prehension, and fitting the latter for biped progression,—and a relatively-larger brain, rendering it probable that the psychical faculties of which it is the instrument would be more elevated and more predominant,—yet there he must stop; since he cannot discover in Man's corporeity the faintest indication of those Intellectual and Moral attributes by which he holds himself to be specially distinguished from the brute creation, of that Progressive Reason which draws even the Infinite within its scope, of that upward aspiration after Truth and Goodness which ranges even beyond his intellectual conception, of that yearning after a purely Spiritual existence which refuses to recognize in bodily decay anything but the liberation of the imprisoned Soul. These are facts of Man's nature not less necessary to be taken into account in the estimation of his position in the Universe, than those which are supplied by his bodily organization; and it is not surprising that by a too exclusive regard to them, many eminent Naturalists, from Aristotle downwards, have been led to maintain that Man ought not to be included in the Animal Kingdom at all, but should be ranked in a Kingdom by himself. This, however, is a position which cannot be consistently held by any one who recognizes Anatomical structure as the true basis of Zoological classification. For granting that Man is distinguished from every other form of terrestrial being by psychical attributes which bring him into relation with Infinite Intelligence, he does not the less belong to the Animal Kingdom in his present stage of existence, in virtue of his possession of every attribute by which an Animal is characterized, and the absence of any peculiarity whatever in his organization which can be shown to remove him from that category. And since it is only *as an animal* that he is taken cognizance of by the Zoologist, it is only with his structural characters that the Zoologist should concern himself. In this point of view it appears to the author clearly demonstrable that the structural distinctions by which Man is separated from the higher Apes are much smaller in amount than those by which the latter are separated from the lower Quadrumana; and hence that the Linnæan association of *Man* and the *Quadrumana* in the same primary group is much more correct than the ordinal separation of the *Bimana* and *Quadrumana* maintained by Cuvier, and *à fortiori* than the proposition of Prof. Owen to rank Man in a distinct sub-class.

18. As the ordinal separation of the *Bimana* from the *Quadrumana* has come to be generally accepted upon the authority of Cuvier, it will be desirable to begin by examining into the validity of the characters on which it rests; comparing, in the first place, the hand and the foot of Man with the corresponding extremities of the higher Apes; and then inquiring whether the differences which they respectively present, either surpass in *degree* those with which we meet in a like comparison between the extremities of the higher Apes and those of the lower Monkeys, or can be justly held to depart from them in *kind*. There is in Man, what we observe in none of the Mammalia which approach him in other respects, a complete distinction in the character of the anterior and posterior extremities; the former being adapted for prehension alone, and the latter

almost exclusively for support and progression: and thus each function is performed with much greater completeness, than it can be when two such opposite purposes have to be united. "That," says Cuvier, "which constitutes the *hand*, properly so called, is the faculty of opposing the thumb to the other fingers, so as to seize upon the most minute objects; a faculty which is carried to its highest degree of perfection in Man, in whom the whole anterior extremity is free, and can be employed in prehension." The peculiar prehensile power possessed by the *Hand* of Man, is chiefly dependent upon the size and power of the thumb; which is more developed in him, than it is in the highest Apes (Fig. 1). The thumb of the Human hand can be brought into exact opposition to the extremities of all the fingers, whether singly or in combination; whilst in those Quadrumana which most nearly approach Man, the thumb is so short, and the fingers so much elongated, that their tips can scarcely be brought into opposition; and the thumb and fingers are so weak, that they can never be opposed to each other with any degree of force. Hence, although well suited to cling round bodies of a certain size, such as the small branches of trees, &c., the anterior extremities of the Quadrumana can neither seize very minute objects with such precision, nor support large ones with such firmness, as are essential to the dexterous performance of a variety of operations for which the hand of Man is admirably adapted. This adaptation, however, is not obtained by means of any new instrumentality; for the anterior extremity of the Orang or Chimpanzee possesses not only every bone, but every muscle, which is found in that of Man; and its only structural differences consist in the proportionate development of the several components of these organs respectively.—But the functional powers of the anterior extremity are not related solely to its own structure; since the use that can be made of the limb depends in part upon its relations to the body at large, the general conformation of which must be adapted to turn its special capacity to advantageous account. Thus while the arm of the higher Apes has as wide a range of motion as

FIG. 1.

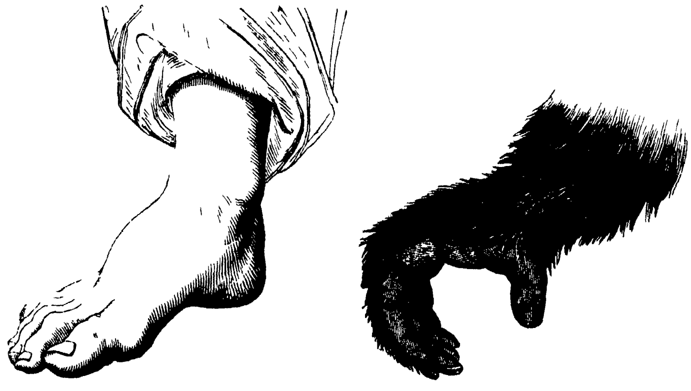


Hand of *Man*, compared with anterior extremity of *Orang*.

that of Man, so far as its articulation is concerned, it is only when the animal is in the erect attitude that the limb can have free play. And even the most perfect organization of the hand as an instrumental structure would be comparatively valueless, without the *mind* by which its actions are prompted, and the *senses* by which they are guided.

19. The *Foot* of Man, in like manner, differs from that of the higher Apes, in those characters which specially adapt it to the support of the body in the erect posture, and to biped progression; in which adaptation it loses much of that prehensile power which the posterior extremities of the higher Quadrumana possess almost equally with their anterior. The Human foot is, in proportion to the size of the whole body, larger, broader, and stronger, than that of any other Mammal save the Kangaroo. Its plane is directed at right angles to that of the leg; and its sole is concave, so that the weight of the body falls on the summit of an arch, of which the os calcis and the metatarsal bones form the two points of support. This arched form of the foot, and the contact of the whole plantar surface with the ground, are peculiarly noticeable in Man; most of the Apes having the os calcis small, straight, and more or less raised from the ground, which they touch, when standing erect, with the outer side only of the foot (Fig. 2). The function of the *hallux*, or great-toe, moreover, is strikingly contrasted in Man and the Apes; for whilst in the latter it is nearly as opposable as the thumb, and can be used to almost the same degree as an instrument of prehension, it chiefly serves in the former to extend the basis of support, and to advance the body in progression. But neither in its osteology nor in its myology is there any essential difference between the foot of Man and the posterior extremity of the higher Apes; for every bone and every muscle in the one has its counterpart in the other; and there is nothing which really assimilates the posterior to the anterior extremity of the Ape, or entitles the former to be considered as a hand, save the opposability of the great-toe. It is certain, moreover, that this faculty is not originally wanting in Man, although it

FIG. 2.



Foot of *Man*, compared with posterior extremity of *Orang*.

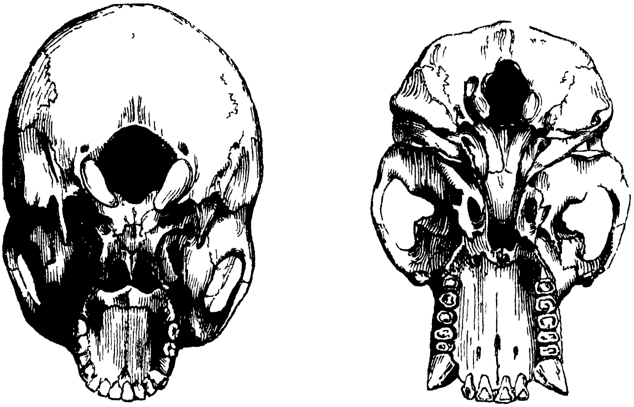
may be destroyed by the disuse produced by the habit of enclosing the foot in rigid investments; for among nations by whom that habit is not practised, we often find that the great-toe can be sufficiently opposed to the other toes to render the foot a useful instrument of prehension, and that many actions are commonly performed by its means, which we are accustomed to regard as requiring *manual* agency. And in the case of individuals among ourselves, who have either been congenitally deficient in the anterior extremities, or who have subsequently lost them, practice only has been required to enable the posterior to be turned to the like account.

20. When the comparison, of which the leading points have now been sketched, is extended further, we meet with differences that cannot but be accounted of far greater importance, both in degree and in kind, than those already enumerated. Thus in the entire group of *Platyrrhine* Monkeys, we find that the thumb is not opposable, but ranges with the other digits, so that it can only be used consentaneously with them in the act of prehension; while in the *Ateles*, or Spider Monkey, the thumb is altogether wanting, and although a great-toe is present, it can neither be used like that of Man for support, nor be opposed to the other digits as in the higher Quadrumana, the posterior and anterior extremities being strikingly assimilated in structure, and being alike adapted to serve only as *claspers*. Among the Baboons and Lemurs, moreover, we find that the conformation alike of the anterior and of the posterior extremities is such as to assimilate them at least as much to the lower *quadrupedal* as to the higher *quadrumanous* type; so that between the two extremes of the series of which the anthropoid Apes are the highest and the Baboons and Lemurs are the lowest members, there is a far wider interval, as regards the conformation of the extremities, than that which separates the former from Man.

21. The next series of distinctive characters to be considered, are those by which Man is adapted to the erect attitude.—On examining his *Cranium*, we remark that the occipital condyles are so placed, that a perpendicular dropped from the centre of gravity of the head would nearly fall between them, so as to be within the base on which it rests upon the spinal column. The foramen magnum is not placed in the centre of the base of the skull, but just behind it; so that the greater specific gravity of the posterior part of the head, which is entirely filled with solid matter, is compensated by the greater length of the anterior part, which contains many cavities. There is, indeed, a little over-compensation, which gives a slight preponderance to the front of the head, so that it drops forwards and downwards when all the muscles are relaxed; but the muscles attached to the back of the head are far larger and more numerous than those in front of the condyles, so that they are evidently intended to counteract this disposition; and we accordingly find ourselves able to keep up the head for the whole day with so slight and involuntary an effort that no fatigue is produced by it. Moreover, the plane of the foramen magnum and the surfaces of the condyles have a nearly horizontal direction when the head is upright; and thus the weight of the skull is laid vertically upon the top of the vertebral column.—If these arrangements be compared with those which prevail in other Mammalia, it will be found that the foramen and condyles are placed in the latter much nearer the back of the head, and that their plane is more oblique. Thus,

whilst the foramen magnum is situated in Man just behind the centre of the base of the skull, it is found in the Chimpanzee and Orang Outan to occupy the middle of the posterior third (Fig. 3); and, as we descend through the scale of Mammalia, we observe that it gradually approaches the *back* of the skull, and at last comes nearly into the line of its longest diameter, as we see in the Horse. Again, in all Mammalia except Man, the plane of the condyles is oblique, so that, even if the head were equally balanced upon them, the force of gravity would tend to carry it forwards and downwards; in Man, the angle which they make with the horizon is very small; in the Orang Outan, it is as much as 37°; and in the Horse, their plane is vertical, making the angle 90°. If, therefore, the natural posture of Man were horizontal, the plane of his condyles would be brought, like that of the Horse, into the vertical position; and the head, instead of being nearly balanced on the summit of the vertebral column, would hang at the end of the neck, so that its whole weight would have to be supported by some external and constantly-acting power. But for this, there is neither in the skeleton, the ligamentous apparatus, nor the muscular system of Man, any adequate provision; so that in any other than the vertical position, his head, which is relatively heavier than that of most Mammalia, would be supported with more difficulty and effort than it is in any other animal.

FIG. 3.



View of the base of the Skull of *Man*, compared with that of the *Orang Outan*.

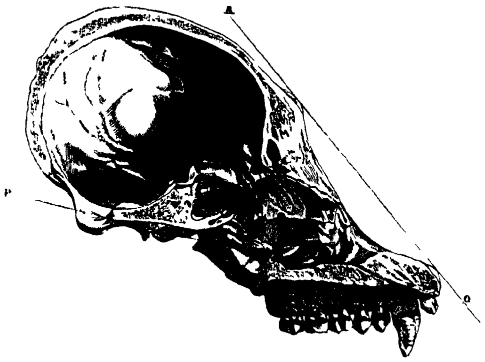
22. The position of the *Face* immediately beneath the brain, so that its front is nearly in the same plane as the forehead, is peculiarly characteristic of Man; for in the skulls of the Chimpanzee and Orang, which approach nearest to that of Man, the cranial portions are rather posterior to, than above, the facial (Figs. 4, 7). The projection of the muzzle, taken in connection with the obliquity of the condyles, is another evidence of want of perfect adaptation to the erect posture; whilst the absence of prominence in the face of Man shows that none but the erect position can be natural to him. For supposing that, with a head formed and situated

as at present, he were to move on all-fours, his face would be brought into a plane parallel with the ground; so that as painful an effort would be required to examine with the eyes an object placed in front of the body, as is now necessary to keep the eyes fixed on the zenith; the nose would then be incapacitated for receiving any other odorous emanations than those proceeding from the earth or from the body itself; and the mouth could not touch the ground without bringing the forehead and chin also into contact with it. The oblique position of the condyles in the Quadrumana enables them, without much difficulty, to adapt the inclination of their heads either to the horizontal or to the erect posture; but the natural position, in the highest among them, is unquestionably one in which the spinal column is inclined, the body being partially thrown forwards so as to rest upon the anterior extremities; and in this position, the face is directed forwards without any effort, owing to the mode in which the head is obliquely articulated with the spine (Fig. 7).

23. The Cranium of Man is further distinguished from that of the anthropoid Apes, not merely by its great capacity, but also by its smoothness; its surface being almost entirely deficient in those ridges for the attachment of muscles, which are remarkably strong in both the Chimpanzee and the Orang, and which impart to its configuration somewhat of a carnivorous aspect. This aspect is strengthened by the great depth of the temporal fossa, and by the extent and strength of the zygomatic arch; features that are most remarkably developed in the *Troglodytes gorilla* (Fig. 7). Moreover, the jaws in even the most degraded races of Man project far less from the general plane of the face, than they do in the Apes; and his teeth are arranged in a continuous series, without any hiatus or any considerable difference in length: whilst all the Apes, in their adult state at least, are furnished with canine teeth of extraordinary length, between the sockets of which and those of the adjoining teeth (anteriorly in the upper jaw, and posteriorly in the lower,) there is a vacant space or 'diastema.' Even in the most prognathous Human skulls, moreover, the incisors meet each other much more nearly in the same axis than they do in the anthropoid Apes, in which they form an angle with each other that is not nearly so divergent. The fusion of the intermaxillary or premaxillary bones with the superior maxillary, at an early period of fœtal life, is a remarkable character of the Human cranium, as distinguishing it from that of the Apes, in which the intermaxillary bones remain separate to a much later period, sometimes differing also very considerably both in size and shape. Thus, in the *Troglodytes gorilla*, these bones are not only remarkable for their prominence, but also for their upward extension round the nostrils, so that they completely exclude the maxillary bones from their borders, and form the basis of support for the nasal bones; and although they coalesce with the maxillaries at and near the alveolar portion, they remain separate elsewhere. The lower jaw of Man is remarkable for that prominence at its symphysis which forms the chin; and although this, also, is least developed in the most prognathous Human crania, yet it is never so deficient as it is in the lower jaw of the Chimpanzee and Orang.—It is curious to observe that the skulls of the *young* of Man and of the anthropoid Apes resemble one another much more than do those of the *adults;* each tending to diverge, in its advance towards full development, from a type which seemed almost similar in both (Figs. 4, 5, 6).

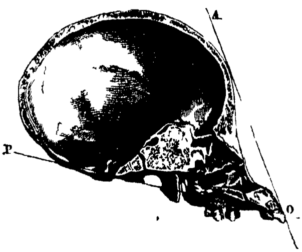
It is at the time of the second dentition, that the muzzle of the anthropoid Apes acquires its peculiar elongation and consequent projection in front of the forehead (Figs. 3, 4); and the whole cast of the features is altered at the same time, so that it approaches much more to that of the lower Quadrumana than would be supposed from observation of the young animal only.* In the Human subject, on the other hand, we see that although in the advance from childhood to adult age, there is a progressive enlargement of the face in proportion to the capacity of the cranial cavity, this augmentation is comparatively small in amount, and but little affects the general configuration of the cranium.†

Fig. 4.



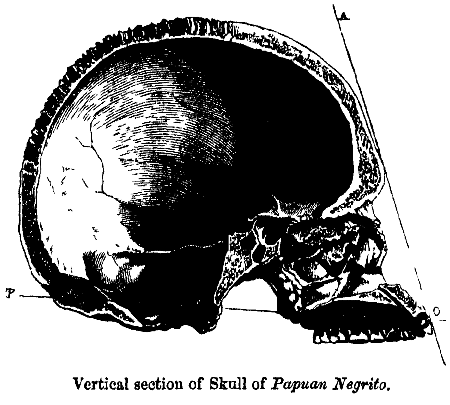
Vertical section of Skull of *Adult Orang.*

Fig. 5.



Vertical section of Skull of *Young Orang.*

Fig. 6



Vertical section of Skull of *Papuan Negrito.*

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* None but young specimens of the Chimpanzee and Orang Outan have ever been brought alive to this country; and they have never long survived the period of their second dentition.

† See Prof. Owen's Papers on the Anatomy of the Orang and Chimpanzee, in the "Zoological Transactions," vols. i. and iii.; and Prof. Vrolik in the Art. *Quadrumana* in the "Cyclopædia of Anatomy and Physiology," vol. iv.

24. The great size of the *cranial* portion of the skull in Man, as compared with the *facial*, produces a marked difference between his 'facial angle' and that of even the highest Quadrumana. According to Camper, who first applied this method of measurement, the 'facial angle' of the average of European skulls is 80°, whilst in the ideal heads of the Grecian gods it is increased to 90°; on the other hand, in the skull of a Kalmuck he found it to be 75°, and in that of a Negro only 70°; and applying the same system of measurement to the skulls of Apes, he found them to range from 64° to 60°. But these last measurements were all taken from young skulls, in which the forward extension of the jaws, which takes place on the second dentition, had not yet occurred. In the adult Chimpanzee, as Prof. Owen has shown, the 'facial angle' (Figs. 4, 5, 6, AOP) is no more than 35°, and in the adult Orang only 30°; so that instead of the Negro being nearer to the Ape than to the European, as Camper's estimate would make him, the interval between the most degraded Human races and the most elevated Quadrumana, is considerably greater than between the highest and the lowest forms of Humanity. It must be borne in mind, however, that the 'facial angle' is so much affected by the degree of prominence of the jaws, that it can never afford any certain information concerning the elevation of the forehead and the capacity of the cranium; all that it can in any degree serve to indicate, being the relative proportion between the facial and the cranial parts of the skull. This proportion is far more correctly determined, as Prof. Owen has shown,* by vertical sections of the skulls to be compared, through their median planes (Figs. 4, 5, 6); and from an extended comparison of such sections it appears that whilst the difference between the cranial cavity of the higher Apes and that of Man is rather one of relative size than of conformation, there is a far more strongly-marked difference, not only in relative size but also in conformation, between the cranial cavities of the higher and those of the lower Quadrumana, the latter being not only far less capacious in proportion to the size of the body, but being also disposed in such a manner that its long diameter comes to be continuous (as in Quadrupeds generally) with the axis of the spinal canal, instead of crossing it nearly at right angles as in Man.

25. The *Vertebral Column* in Man, although not absolutely straight, has its curves so arranged, that, when the body is in an erect posture, a vertical line from its summit would fall exactly on the centre of its base. It increases considerably in size in the lumbar region, so as altogether to be somewhat pyramidal in form. The lumbar portion in the Chimpanzee and Orang is not of the same proportional strength, and contains but four vertebræ instead of five. The processes for the attachment of the dorsospinal muscles to this part are peculiarly large and strong in Man; and this arrangement is obviously adapted to overcome the tendency which the weight of the viscera in front of the column would have to draw it forwards and downwards. On the other hand, the spinous processes of the cervical and dorsal vertebræ, which in other Mammalia are large and strong for the attachment of the ligaments and muscles that support the head, and which are peculiarly pronounced in the Gorilla (Fig. 7), have comparatively little prominence in Man, his head being nearly balanced on the top of the column.—The base of the Human vertebral

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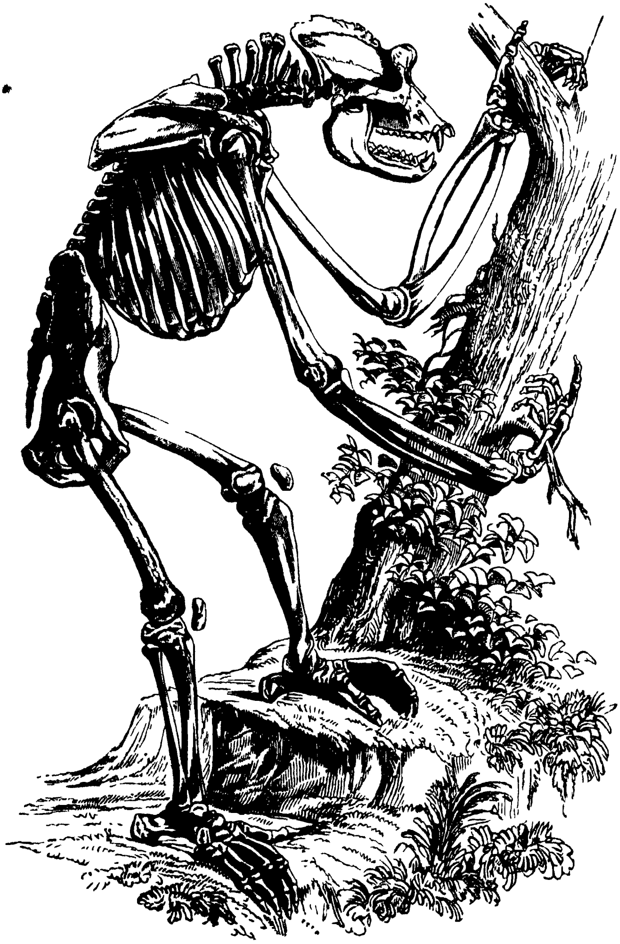
* "Zoological Transactions," vol. iv., p. 77 *et seq.*

column is placed on a sacrum of greater proportional breadth than that of any other animal; this sacrum is fixed between two widely-expanded ilia; and the whole *pelvis* is thus peculiarly broad. In this manner, the femoral articulations are thrown very far apart, so as to give a wide basis of support; and by the oblique direction of the pelvis, the weight of the body is transmitted almost vertically from the top of the sacrum to the upper part of the thigh-bones. The pelvis of the anthropoid Apes is very differently constructed; as will be seen in the adjoining PLATE, in which the skeleton of the Orang is placed in proximity with that of Man. It is much larger and narrower; its alæ extend upwards rather than outwards, so that the space between the lowest ribs and the crest of

FIG. 7.



Skeleton of *Troglodytes Gorilla.*

the iliac bones is much less than in Man; their surfaces are nearly parallel to that of the sacrum, which is itself longer and narrower; and the axis of the pelvis is nearly parallel with that of the vertebral column. The position of the Human femur in which its head is most securely retained in its deep acetabulum, is that which it has when supporting the body in the erect attitude; in the Chimpanzee and Orang its analogous position is at an oblique angle to the long axis of the pelvis, so that the body leans forwards in front of it (Fig. 7); in many Mammalia, as in the Elephant, it forms nearly a right angle with the vertebral column; and in several others, as the Horse, Ox, &c. the angle which it makes with the axis of the pelvis and vertebral column is acute. In these respects, then, the skeleton of Man presents an adaptation to the erect posture, which is exhibited by that of no other Mammal; but that of the anthropoid Apes presents a far nearer approximation to the Human model in all the foregoing particulars, than it does to that of the lower Quadrumana.

26. There is a considerable difference in the form of the *trunk*, between Man and most other Mammalia; for his thorax is expanded laterally, and flattened in front, so as to prevent the centre of gravity from being carried too far forwards; and his sternum is short and broad. Between the bony walls of the thorax and the margin of the pelvis, a considerable space intervenes, which is occupied solely by muscles and tegumentary membranes; and these would be quite insufficient to sustain the weight of the viscera, if the habitual position of the trunk had been horizontal.—In these particulars, however, the most anthropoid Apes agree more or less completely with Man.

27. The *lower extremities* of Man are remarkable for their relative length, which is greater than that which we find in any other Mammalia, except the Kangaroo tribe. The chief difference in their proportions between Man and the semi-erect Apes, is seen in the thigh; and it is from the relative length of this part in him, as well as from the comparative shortness of his anterior extremities, that his hands only reach the middle of his thighs, whilst in the Chimpanzee they hang on a level with the knees (Fig. 7), and in the Orang they descend to the ankles (PLATE). The Human femur is distinguished, however, by its form and position, as well as by its length. The obliquity and length of its neck still further increase the breadth of the hips; whilst they cause the lower extremities of the femora to be somewhat obliquely directed towards each other, so that the knees are brought more into the line of the axis of the body. This arrangement is obviously of great use in facilitating the purely *biped* progression of Man, in which the entire weight of the body has to be alternately supported on each limb; for if the knees had been kept further apart, the whole body must have been swung from side to side at each step, so as to bring the centre of gravity over the top of each tibia; as is seen to a certain extent in the female sex, whose walk, owing to the greater breadth of the pelvis and the separation between the knees, is less steady than that of the male. There is also a marked difference between the knee-joint of Man, and that of even the highest Apes. In the former, the opposed extremities of the femur and the tibia are so expanded as to present a very broad articulating surface, and the internal condyle of the femur being the longer of the two, the two condyles are in the same horizontal plane in the usual oblique position of that bone; so that by this

arrangement, the whole weight of the body, in its erect posture, falls vertically on the top of the tibia, when the joint is in the firmest position in which it can be placed. The knee-joint of the Orang, on the other hand, is comparatively deficient in extent of articulating surface; and its whole conformation indicates that it is not intended to serve as more than a partial support.—In regard to the general conformation of the bones of the extremities, it may be most explicitly affirmed that the differences which undoubtedly exist between Man and the anthropoid Apes are much less considerable than those which present themselves between the latter and those Baboons and Lemurs whose ordinary mode of progression is *quadrupedal.* And thus, after contrasting one part after another of the skeleton of Man with the corresponding parts of the skeleton of the higher Apes, we are led in every instance to the same conclusion. It is quite true that between Man and those Apes which approach him most closely, there is a wider *hiatus* than we usually meet with between the members of the Quadrumanous series, which as a whole presents a remarkably gradational transition between its higher and lower forms; and the existence of this *hiatus* has been used as an argument for ranking Man in a distinct Order. But since, as we ascend that series, we witness a gradual tendency towards the anthropoid form, and since in passing from the highest Apes to Man we only come somewhat abruptly upon the culmination of that ascent without being led off in any other direction, it would be contrary to the whole idea of Zoological classification to place Man in a distinct category from them as regards his corporeal structure, whatever we may think it right to do when we take his psychical constitution into account.* And it is to be borne in mind that this *hiatus*—like many similar gaps in our classification of existing animals which have been filled up by the progress of palæontological research—*may* be simply due to that extinction of intermediate forms which (there is constantly increasing reason to believe) has taken place in past ages of the Earth's history, to an extent of which the remains hitherto known to us afford but a very imperfect idea. That it *may not* be completely bridged-over by such intermediate links, no one has any right to affirm upon negative evidence only; more especially in the face of the positive evidence afforded by the recent discovery of a very remarkable fragment of a skull, which, while unquestionably Human, resembled that of the Gorilla in the comparative lowness of its vault, the smallness of its capacity, and the extraordinary prominence of its superciliary ridges.†

28. The most characteristic peculiarity of the Human *Myology*, is the great development of those muscles of the trunk and limbs, which contribute to the maintenance of the erect posture. Thus, the gastrocnemii, and the other muscles which tend to keep the leg erect upon the foot, form a much more prominent 'calf' than is seen either in the most anthropoid Apes, or in any other animal. So, again, the extensors of the leg upon the thigh are much more powerful than the flexors; a character

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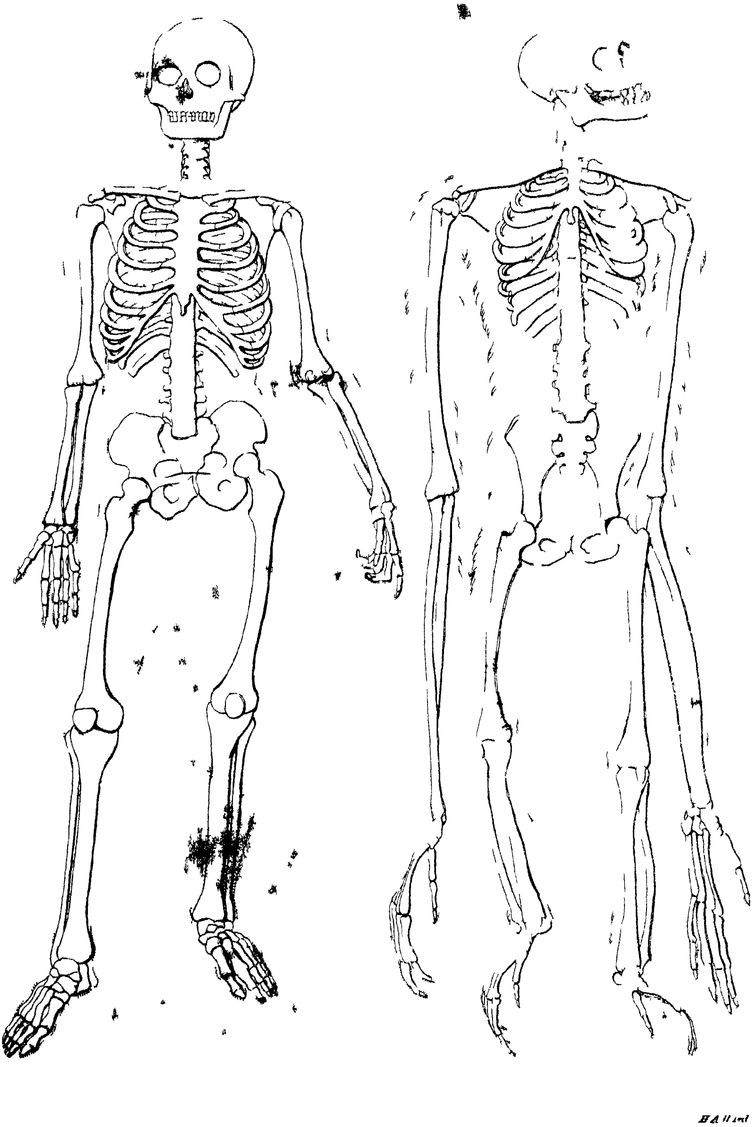
* We meet with a similarly abrupt transition at the other extremity of the series, in the *Cheiromys* or Aye-aye; an animal which Zoologists now agree to rank among the Quadrumana in virtue of its general Lemurine affinities, although in dentition and several other particulars it bears so strong a resemblance to the Rodents as to have been placed among them by Cuvier.

† See "Natural History Review," vol. i., 1861, p. 155; and Prof. Huxley 'On some Fossil Remains of Man,' in his "Evidence as to Man's Place in Nature," 1863.



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COMPARATIVE VIEW OF THE SKELETON OF MAN,

AND THAT OF THE OURAN OUTAN

which is peculiar to Man. The glutæi, by which the pelvis is kept erect upon the thigh, are of far greater size than is elsewhere seen. The superior power of the muscles tending to draw the head and spine backwards, has been already referred-to. Among the differences in the attachment of individual muscles, it may be noticed that the 'flexor longus pollicis pedis' proceeds in Man to the great toe alone, on which the weight of the body is often supported; whilst it is attached in the Chimpanzee and Orang to the three middle toes also. The 'latissimus dorsi' is destitute in Man of that prolongation attached to the olecranon, which is found in the lower Mammalia, and which exists even in the Chimpanzee, probably giving assistance in its climbing operations. The larger size of the muscles of the thumb, is, as might be expected, a characteristic of the hand of Man; although the number of muscles by which that digit is moved, is the same in the Chimpanzee as in the Human subject. The separation of the 'extensor digiti indicis,' however, as a distinct muscle, is peculiar to Man.

29. The *Visceral* apparatus of Man presents very few characteristic peculiarities, by which it can be distinguished from that of the higher Quadrumana; among the most remarkable is the absence of the laryngeal pouches, which exist even in the Chimpanzee and Orang Outan, as dilatations of the laryngeal ventricles. Of the anatomy of the last-named animals in their *adult* condition, however, we know as yet too little to enable its conformity to that of Man to be confidently pronounced-upon.

30. The *Brain* of Man does not differ so much in conformation from that of the Chimpanzee and Orang, as the superiority of his mental endowments might have led us to anticipate. The following are the principal differences which it seems to present:—1. The mass of the entire brain is considerably larger in proportion to that of the body, and in proportion also to the diameter of the spinal cord and of the nerves which are connected with it.—2. In the external configuration of the Cerebrum, we notice that its *anterior* lobes project further beyond the Rhinencephalon, or Olfactive Ganglion, than they do in the highest Quadrumana; a difference which is well marked in the sectional contour of the brain-case, the rhinencephalic fossa of the Orang (Fig. 4, *rh*) being at its most anterior part; whilst even in the least elevated forms of the Human skull, this fossa (of which the cribriform plate of the ethmoid bone constitutes the floor) has no inconsiderable part of the cranial cavity in front of it (Fig. 6, *rh*).—3. The *posterior* lobes also are more developed, so as to project further beyond the Cerebellum than they do in the Quadrumana generally.—4. The Convolutions are more numerous and complex, and usually more or less unsymmetrical, and the sulci are deeper. It appears, however, that in the lower races of Mankind, the brain presents, both in the simplicity and the precise symmetry of its convolutions, a much closer approximation to the Quadrumanous type than it does in the higher.—5. On examining the internal structure, it is found that the peripheral layer of grey matter is thicker, the corpus callosum extends further backwards, and the posterior cornua of the lateral ventricles are relatively longer and larger than they usually are in Quadrumana.*—6. The Cerebellum, also, is proportionally larger.

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* It has been recently asserted by Prof. Owen ("Journal of the Proceedings of the Linnæan Society," vol. ii. p. 19) that the existence of the posterior lobes of the Cerebrum, of the posterior cornua of the lateral ventricles, and of the hippocampus

31. The small size of the face of Man, compared with that of the cranium, is an indication that in him the *senses* are subordinate to the *intelligence*. Accordingly we find that while he is surpassed by many of the lower animals in acuteness of sensibility to light, sound, &c., he stands pre-eminent in the power of comparing and judging of his sensations, and of thence drawing conclusions as to their objective sources. Moreover, although none of his senses are very acute in his natural state, they are *all moderately* so; and they are capable of being wonderfully improved by practice, when circumstances strongly call for their exercise. This seems especially the case with the *tactile* sense, of which Man can make greater use than any other animal, in consequence of the entire freedom of his anterior extremities; although there are many which surpass him in their power of appreciating certain classes of tactile impressions.—So, again, Man's nervo-muscular power is inferior to that of most other animals of his size: the full-grown Orang, for example, surpasses him both in strength and agility; and the Gorilla, according to the statements of the Negroes who have encountered it, is more than a match for any single man, and is almost certain to destroy any human opponent once within his grasp.—The absence of any natural weapons of offence, and of direct means of defence, are remarkable characteristics of Man, and distinguish him not only from the lower Mammalia, but also from the most anthropoid Apes; in which it is obvious (both from their habits and general organization) that the enormous canines have no relation to a carnivorous regimen, but are instruments of warfare. On those animals to which Nature has denied weapons of attack, she has bestowed special means either of passive defence, of concealment, or of flight; in each of which Man is relatively deficient. Yet by the superiority of his reason he has been enabled not only to resist the attacks of other animals, but even to bring them into subjection to himself. His intellect can scarcely suggest the mechanism which his hands cannot frame; and he has devised and constructed arms more powerful than those which any creature wields, and defences so secure as to defy the assaults of all but his fellow-men.

32. Man is further remarkable for his extraordinary power of adaptation to varieties in external condition, which renders him to a great extent independent of them. He is capable of sustaining the highest as well as the lowest extremes of temperature and of atmospheric pressure. In the former of these particulars, he is strikingly contrasted with the anthropoid Apes; the Gorilla and Chimpanzee being restricted to the hottest parts of Africa, and the Orang Outan to the tropical portions of the Indian Archipelago; and neither of these animals being capable of living in temperate climates without the assistance of artificial heat, even with the aid of which they have not hitherto long survived their second dentition. So, again, although Man's diet seems naturally of a mixed character, he can support himself in health and strength either on an exclusively vegetable diet or on an almost exclusively animal regimen.

minor which projects into each cornu, is peculiar to the genus *Homo*. How strangely inconsistent is this assertion with the well-known and certainly-ascertained facts of the case, has been conclusively shown by Prof. Huxley in his Memoir 'On the Zoological Relations of Man with the Lower Animals,' in the "Natural History Review," Jan. 1861, p. 71 *et seq.*; and the chief points of the controversy have since been succinctly stated in his "Evidence as to Man's Place in Nature," 1863.

33. The slow growth of Man, and the length of time during which he remains in a state of dependence, are peculiarities that remarkably distinguish him from all other animals. He is unable to obtain his own food during at least the first three years of his life; and he does not attain to his full bodily stature and mental capacity until he is more than twenty years of age. This retardation of the developmental process seems to have reference to the high grade which it is ultimately to attain; for everywhere, throughout the Organized Creation, do we observe that the most elevated forms are those which go through the longest preparatory stages, and of which the evolution is most dependent upon the assistance afforded by the parental organism during its earlier periods. The peculiar prolongation of this state of dependence in the Human species, has a most important and evident effect upon the social condition of the race; being, in fact, the chief source of family ties, and affording the opportunity for those processes of education, direct and indirect, which transmit to the rising generation the influence of the intellectual culture and moral training of the past.

34. Still, however widely Man may be distinguished from other animals by these and other particulars of his structure and economy, he is yet more distinguished by those *mental* endowments, and by the habitudes of life and action thence resulting, which must be regarded as the essential characteristics of Humanity. It is in adapting himself to the conditions of his existence, in providing himself with food, shelter, weapons of attack and defence, &c., that Man's intellectual powers are first called into active operation; but when thus aroused, their development has no assignable limit. The Will, guided by the intelligence, and acted-on by the desires and emotions, takes the place in Man of the Instinctive propensities which are usually the immediate springs of action in the lower animals; for although, among the most elevated of these, a high amount of Intelligence is exhibited, yet its operations seem to be always directly attributable to external suggestions, present or remembered; and the character never rises beyond that of the child. In fact, the correspondence between the psychical endowments of the Chimpanzee, and those of a Child of three years old who has not yet begun to speak, is very close.—One of the most important aids in the use and development of the Human mind, is the capacity for *articulate speech;* of which, so far as we know, Man is the only animal in possession. There is no doubt that many other species have certain powers of communication between individuals; but these are probably very limited, and of a kind more allied to "the language of signs" than to a proper verbal language. In fact, it is obvious that the use of a language composed of a certain number of distinct sounds, combined into words in a multitude of different modes, requires a power of intellectual abstraction and generalization, in which it appears that the lower animals are altogether deficient. So, again, verbal language affords the only means whereby abstract ideas can be communicated; and those who have perused the interesting narrative given by Dr. Howe of his successful training of Laura Bridgeman, will remember how marked was the improvement in her mental condition, from the time when she first apprehended the fact that she could give such distinct expression to her thoughts, feelings, and desires, as should secure their being comprehended by others.

35. The *capacity for intellectual progress* is a most remarkable peculiarity of Man's psychical nature. The instinctive habits of the lower Animals are limited, are peculiar to each species, and have immediate reference to their bodily wants. Where a particular adaptation of means to ends, of actions to circumstances, is made by an individual, the rest do not seem to profit by that experience; so that, although the instincts of particular animals may be modified by the training of Man, or by the education of circumstances, so as to show themselves after a few generations under new forms, no elevation in intelligence appears ever to take place spontaneously, no psychical improvement is manifested in the species at large. In Man, on the other hand, we observe not merely the capability of profiting by experience, but the determination to do so; which he is enabled to put into action by the power which his Will (when properly disciplined) comes to possess, of directing and controlling his current of thought, by fixing his attention upon any subject which he desires to keep before his mental vision. This power, so far as we know, is peculiar to Man; and the presence or absence of it constitutes the difference between a being possessed of power to determine his own course of thought and action, and a mere thinking automaton.

36. Man's capacity for progress is connected with another element in his nature, which it is difficult to isolate and define, but which interpenetrates and blends-with his whole psychical character. "The Soul," it has been remarked, "is that side of our nature which is in relation with the Infinite;" and it is the existence of this relation, in whatever way we may describe it, which seems to constitute one of the most distinctive peculiarities of Man. It is in the desire for an improvement in his condition, occasioned by an aspiration after something nobler and purer, that the main-spring of human progress may be said to lie; among the lowest races of mankind, the capacity exists, but the desire seems dormant. When once thoroughly awakened, however, it seems to "grow by what it feeds on;" and the advance once commenced, little external stimulus is needed; for the desire increases at least as fast as the capacity. In the higher grades of mental development, there is a continual looking-upwards, not (as in the lower) towards a more elevated Human standard, but at once to something beyond and above Man and Material Nature. This seems the chief source of the tendency to believe in some unseen existence; which may take various forms, but which seems never entirely absent from any race or nation, although, like other innate tendencies, it may be deficient in individuals. Attempts have been made by some travellers to prove that particular nations are destitute of it; but such assertions have been based only upon a limited acquaintance with their habits of thought, and with their outward observances; for there are probably none who do not possess the idea of some invisible Power, external to themselves, whose favour they seek, and whose anger they deprecate, by sacrifice and other ceremonials. It requires a higher mental cultivation than is commonly met-with, to conceive of this Power as having a spiritual existence; but wherever the idea of Spirituality can be defined, this seems connected with it. The vulgar readiness to believe in ghosts, demons, &c., and the vagaries of the so-called 'Spiritualists' of recent times, are only irregular or depraved manifestations of the same tendency. Closely connected with it, is the desire to participate in this spiritual

existence; of which the germ has been implanted in the mind of Man, and which, developed as it is by the mental cultivation that is almost necessary for the formation of the idea, has been regarded by philosophers in all ages as one of the chief natural arguments for the immortality of the soul. By this immortal soul, Man is connected with that higher order of being, in which Intelligence exists, untrammelled by that corporeal mechanism through which it here operates; and to this state,—a state of more intimate communion of mind with mind, and of creatures with their Creator,—he is encouraged to aspire, as the reward of his improvement of the talents here committed to his charge.

CHAPTER III.

OF FOOD, AND THE DIGESTIVE PROCESS.

1. *Of Food, its Nature and Destination.*

37. The substances which are required by Animals for the development and maintenance of their fabric, are of two kinds;—the Organic and the Inorganic. The Organic alone are commonly reckoned as aliments; but the latter are really not less requisite for the sustenance of the body, which speedily disintegrates, if the attempt be made to support it upon any Organic compounds in a state of purity. In all ordinary articles of diet, however, the Inorganic matters are present in the requisite proportion; and hence it is that the necessity which exists for their employment has very commonly escaped notice.

38. The Organic compounds usually employed as food by Man, are partly derived from the Animal, and partly from the Vegetable kingdom; and they may be conveniently arranged under the four following heads:*—1. The *Saccharine* group, including all those substances, derived from the Vegetable kingdom, which are analogous in their composition to Sugar; consisting of oxygen, hydrogen, and carbon alone; and having the first two components united in the proportions to form water. To this group belong starch, gum, woody-fibre, and the cellulose of Plants, which closely resemble each other in the proportion of their elements, and which may be converted into Sugar by chemical processes of a simple kind; whilst Alcohol, which is derived from Sugar by the process of fermentation, has a composition which rather connects it with the next group.—2. The *Oleaginous* group, including oily matters, whether derived from the Vegetable kingdom, or from the fatty portions of Animal bodies. The characteristic of this class lies in the great predominance of hydrogen and carbon, the small proportion of oxygen, and the entire absence of nitrogen.—3. The *Albuminous* group, comprising all those substances, whether derived from the Animal or the Vegetable kingdom, which are closely allied to Albumen, and through it to the Animal tissues gene-

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* Dr. Prout's classification of alimentary substances is here adopted, with a slight modification; not as being altogether unexceptionable, but as being, in the Author's opinion, the most convenient hitherto proposed.

rally, in their chemical composition. In this group a large proportion of azote is united with the oxygen, hydrogen, and carbon of the preceding. —4. The *Gelatinous* group, consisting of substances derived from Animal bodies only, which are closely allied to Gelatine in their composition. These also contain azote; but the proportion of their components differs from that of the preceding.—There are many other substances, however, which, though truly alimentary, and consumed to a considerable amount, cannot be legitimately placed under either of the above heads; such are, for example, the Vegetable Acids, and Pectine or vegetable jelly.

39. Compounds belonging to the *Saccharine* group appear to be widely distributed in the various tissues and fluids of the body. Thus Inosite $C_{12}H_{12}O_{12}$ + 4 Aq. has been found in the heart, liver, lungs, spleen, kidneys, and brain, and occasionally in the voluntary muscles. Grape Sugar $C_{12}H_{12}O_{12}$ + 2 Aq. has been observed in the blood, chyle, and lymph, and there may even be a trace in the urinary secretion of some healthy persons;[*] and Lactose or sugar of milk $C_{12}H_{11}O_{11}$ + Aq. is invariably present in the milk of the Mammal. Analogous compounds are found in certain parts of the nervous centres, in the prostate gland, and in pathological conditions of various other organs; and from the resemblance which these substances present, in their form and reactions, to grains of starch, the term 'corpora amylacea' has been applied to them by Virchow. In the liver, again, a peculiar soluble substance exists analogous to dextrine in its character; this, from the readiness with which it can be converted into sugar, is termed Glycogen by its discoverer Bernard. Lastly, in certain embryonic and uterine structures a homogeneous plasma, called by Rouget Zo-amyline[†] is contained, whose constitution, though probably analogous to starch, has not yet been accurately ascertained. That a great part of these Saccharine and Amyloid compounds are derived directly from the food, is clearly shown by the following experiment of M. Bernard:[‡]— The muscular tissue of a fasting horse was found, on careful examination, to be perfectly free from amyloid substances; but in the muscles of the same animal a few hours after a full meal, abundant evidence of their presence was obtained. But it seems also to be established that compounds presenting a close analogy to sugar may be obtained by the metamorphosis of oleaginous as well as of albuminous substances within the body; of which we have examples in their continued formation in the liver when completely absent in the food, during even the last stages of inanition, and in their presence and gradual increase in the egg of the bird during incubation. Before absorption, Starch is for the most part converted into dextrine and sugar; whilst sugar is itself partially decomposed into lactic and butyric acids. After absorption, decomposition into lactic[§] and ultimately into carbonic

[*] Brücke, "Journal de la Physiologie," vol. ii. 1859, p. 339.

[†] "Journal de la Physiologie," vol. ii. 1859, pp. 83, 308.

[‡] "Leçons," 1859, vol. ii. p. 112.

[§] Lactic Acid $C_6H_5O_5 + H\,O$ is a compound of considerable chemical and physiological interest; for it is related not only to the Saccharine group, but also to both Albuminous and Oleaginous compounds. With the former it has been shown by Kolbe to be closely connected, since it is a product of the oxidation of Alanin, which is isomeric with Sarcosin, a derivative of Kreatine, a well-known product of the retrogressive metamorphosis of Albumen: whilst to the Oleaginous substances it is related by the similarity of its composition to Propionic Acid, which is a product of the oxidation acid takes place. And thus by a process of oxidation or combustion, these compounds become directly subservient to the maintenance of the heat of the body. The small quantity of Sugar naturally present in the blood aids in retaining the carbonate and phosphate of lime in solution, and according to Hoppe, assists that metamorphosis by which fat is generated from the albuminous compounds.* That the Saccharine substances are, *per se*, insufficient for the maintenance of life has been shown by numerous experiments upon animals, and has lately been confirmed (though confirmation was scarcely needed) by the interesting observations of Dr. Hammond on himself.†

40. The Oleaginous compounds which enter so largely into the composition of the body,—being not only stored up in masses in the adipose substance, but also forming constant and important constituents of the muscular, nervous, and other tissues,—are partly introduced into the system from without, and are also partly the result of the chemical metamorphoses effected within the body upon the albuminous and saccharine compounds: by which means the latter become subservient to the nutrition of the several nitrogenous as well as non-nitrogenous tissues. Previous to absorption the oleaginous substances undergo fine division, and, perhaps, to some extent saponification; whilst after their entrance into the circulation they are partly applied to the purposes of nutrition, and partly, there is good reason for believing, combine immediately with oxygen, and thus support the animal heat. Like the saccharine, the oleaginous compounds when consumed alone are wholly incapable of supporting life; and the only benefit that a starving animal obtains from their consumption is the maintenance of its temperature, and a consequent slight prolongation of its life; death occurring, as has been shown by Mr. Savory, when non-nitrogenous food is freely supplied,‡ not from loss of temperature, as in inanition, but from loss of tissue.

41. The substances forming the *Albuminous* group are applicable to the support of the Animal body, both by affording the materials for the nutrition and re-formation of its tissues, and also by serving (if required) for the maintenance of its heat, through the decomposition of which they are susceptible, into hydrocarbonaceous matters adapted for combustion in the lungs, and highly-azotized compounds which pass-off by the kidneys. The proportions of carbon, hydrogen, oxygen, and nitrogen, of

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of Oleic Acid, and it is thus associated with Formic and Butyric Acids. That Lactic Acid is derived from the disintegration of the Albuminous compounds, is strongly indicated by the fact that it is found in greatly increased proportion in muscles which have been previously exercised. It appears to be rapidly decomposed in the blood (Carbonic Acid being left in combination with the bases), since, a few minutes after the introduction of considerable quantities of alkaline lactates into the stomach, the urine is found to be alkaline from the presence of their carbonates.

* "Archiv f. Path. Anat.," x. p. 140.

† Dr. Hammond, "Experimental Researches on Food," Philadelphia, 1857. Dr. Hammond limited himself on one occasion to a diet of about 1¼ lb. of gum per diem, and on another to a similar quantity of starch and water. In both sets of experiments hunger, debility, and febrile excitement were soon experienced, and he was finally compelled to discontinue the gum diet on the fourth day, though he was able to persevere in the use of the starch till the tenth,—a circumstance which was probably partly due to its still retaining a small proportion of gluten, and partly to its not producing such serious disorder of the stomach and bowels as the gum.

‡ "Proceedings of Royal Society," May 1, 1862.

which all these substances are composed, appear to be identical; and they seem all capable of being reduced by the digestive process to a like condition. Hence it is a matter of little consequence, except as regards the proportion of inorganic matters with which they may be respectively united, whether we draw our histogenetic materials from the flesh of animals, from the white of egg (albumen), from the curd of milk (casein), from the grain of wheat (gluten), or from the seed of the pea (legumin). Neither of these substances, however, can long sustain life when it is used by itself; for it has been experimentally ascertained,* that by being made to feed constantly on the same substance (boiled white-of-egg, for instance, or meat deprived of the osmazome that gives it flavour), an animal may be effectually starved; its disgust at such food being such, that even if this be swallowed, it is not digested.†—The organized fabric of Animals contains also a large quantity of *Gelatine.* It seems certain that this substance may be produced out of fibrin and albumen; since in animals that are supported on these, or, at least, consume no gelatine with their food, the nutrition of the gelatinous tissues does not seem to be impaired. The recent experiments of Bischoff and Voit,‡ when taken in conjunction with the inquiries of the commissioners appointed to investigate the subject in Paris and Amsterdam,§ appear to have established that, though gelatine is not destitute of nutritive value, it cannot permanently replace albumen as an article of diet. For a short period it may indeed be serviceably, perhaps even advantageously employed; and the nutritive value which experience has long assigned to soups, broth, &c., whilst partly attributable to the albuminous matters which they hold in solution, may also in some measure be due to the readiness with which their gelatinous constituents can be absorbed and applied to the purposes of nutrition and calorification. The very large quantity of gelatine which Bischoff and Voit found it necessary to make their dog consume in order to maintain its weight,—a quantity of the *dry* gelatine, in fact, equal to the weight of moist flesh on which the animal was ordinarily fed,—is worthy of particular notice, and furnishes an explanation of the negative results which were obtained by previous inquirers. That it rapidly undergoes a decomposition analogous to that of the albuminous compounds, is evident from the observations of Frerichs on the result of the ingestion of large quantities of pure gelatine: this being a marked increase in the proportion of urea in the urine, with an elevation of its specific gravity from 1018 to 1030 or even 1034.

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* Dr. Hammond limited himself for a period of ten days to a diet of about 1¼ lb. of albumen obtained from the serum of bullock's blood, and 4 lbs. of distilled water per diem. Little inconvenience was experienced until the fourth day, when loss of appetite, headache, and debility were felt. The severity of these symptoms rapidly increased, and the disgust which the monotony of the diet occasioned was so great that it was with much difficulty that the albumen could be eaten. On the seventh day, albumen appeared in the urine; and on the 9th, such severe diarrhœa set in that he was compelled to give up the experiment. There was no failure in the maintenance of the temperature of the body, though its weight was notably diminished at the end of the experiment, and the mental faculties remained clear throughout.

† It is very interesting to remark (with Dr. Prout) that, in the only instance in which Nature has provided a *single* article of food for the support of the animal body, she has mingled articles from the first three of the preceding groups. This is the case in *Milk,* which contains a considerable quantity of an albuminous substance, *casein,* which forms its curd; a good deal of *oily* matter, the butter; and no inconsiderable amount of *sugar,* which is dissolved in the whey. The proportions of these vary in different Mammalia, and they depend in part upon the nature of the food supplied to the Animal that forms the milk; but the substances are thus combined in every instance.

‡ "Gesetze der Ernährung," 1860, p. 215.

§ See the Report of the French 'Gelatine Commission,' in the "Compt. Rend." Août, 1841; and that of the Amsterdam Commission in "Het. Instituut," No. 2, 1843, and "Gazette Médicale," Mars 16, 1844.

42. The substances which cannot be arranged under either of the preceding groups, are, for the most part, of the Non-azotized class; and, as they mainly consist of compounds in which the hydrogen and carbon are not combined with their full equivalents of oxygen, they are made to contribute to the calorifying process by undergoing oxidation within the system, so as to be excreted in the form of carbonic acid and water. Some of these, moreover, have very special uses in the economy (§ 46, IV.).

43. Up to a comparatively recent period, attempts have been made to divide all kinds of food, in accordance with their supposed application in the body, into two great classes, called respectively the "histogenetic" or tissue-forming, and the "respiratory" or heat-producing aliments. It was imagined that a definite line could be drawn between the non-azotized, including the oleaginous and saccharine substances, on the one hand, and the azotized, embracing the albuminous group and gelatine, on the other; the former being subservient to the production of heat, the latter to the repair and development of the different tissues. To a certain extent this division is unquestionably based on correct principles. The presence of a large proportion of Nitrogen in all the higher tissues of the Animal body clearly indicates that for their due nutrition some substance containing Nitrogen should be consumed as food; and the justice of this inference has been fully borne out by experiment. In this sense, then, the albuminous and gelatinous substances are truly histogenetic. On the other hand, the large proportion of Carbon and Hydrogen in saccharine and oleaginous compounds naturally suggests that the chief purpose to which they are applied in the body is the maintenance of its temperature by their combination with Oxygen. But the muscular, nervous, and glandular tissues are not composed of albuminous substances alone; they contain, as an essential constituent of their structure, a certain proportion of fat, without which their composition would be imperfect, and the performance of their functions impossible. Such fat then must be considered as "histogenetic" and not as "calorifacient" fat; though like that which exists in the free state in the blood, or is stored-up in the adipose tissue, after having fulfilled its functions, it may be applied by its combustion to the support of the animal heat. In a manner essentially similar, the albuminous substances ingested, whilst partly becoming assimilated and applied to the nutrition of the tissues, are partly also directly decomposed in the blood; the products of their disintegration in both instances combining with oxygen, and yielding a certain amount of heat: so that, like the oleaginous and saccharine substances, they are applied to the carrying out of both provisions, the formation of tissues and the maintenance of an elevated temperature, though undoubtedly in both cases to a very unequal degree. It is therefore impossible to measure the value of any particular kind of food for either purpose by a consideration merely of its ultimate or even of its proximate constitution; since its fitness as an article of diet will also depend upon the facility with which it may be reduced by the digestive process, and afterwards assimilated. Thus an aliment abounding in nutritive matter, may be inferior to one which

really contains a much smaller proportion, if only a part in the first case, and the whole in the second, be readily taken-up by the system.

44. It is obvious that the most *economical* diet will be that in which there is the most perfect apportionment of the several classes of constituents to the wants of the system; and these will vary with the amount of muscular exertion put forth, and with the elevation or depression of the external temperature. Thus, for a man of ordinary habits, and living under a medium temperature, a diet composed of either bread or of animal flesh alone is far from being the most economical. No doubt there are particular conditions of existence, under which life may be advantageously supported upon *animal* food alone. Thus the Guachos of South America, who pass the whole day in the saddle, and lead a life of constant activity resembling that of a carnivorous animal, scarcely ever taste anything but beef; and of this their consumption is by no means great; for the temperature of the surrounding atmosphere is so high, that the body has no occasion to generate more heat than is supplied by the combustion of the hydro-carbonaceous portion of the albumen of the food or of 'waste' of the tissues. Here, then, the demand for histogenetic material being at its maximum, and that for combustive materials at its minimum, the former supplies all that is requisite for the latter. Again, the Esquimaux and other dwellers upon the Arctic seas find in the bodies of the whales, seals, &c., whereon they subsist, that special supply of the very best combustive material, which alone can enable them to maintain their existence in a climate, where the thermometer is for many weeks or months in the year at —40° or even lower, and where the amount of heat which must be generated within the body is four or five times that for which a diet of bread will suffice.—On the other hand, the general experience of the inhabitants of warm climates seems in favour of a diet chiefly or entirely *vegetable;* and its peculiar suitableness appears to consist in its affording an adequate supply of the plastic alimentary substances, in combination with farinaceous matters that give the requisite *bulk* to the food, without affording more combustive material than the system requires,—the quantity of starch which undergoes conversion, and which is introduced as sugar into the circulation, being apparently governed rather by the demands of the respiratory process, than by the amount ingested; and the remainder being voided again unchanged.

45. In a well-arranged system of diet, the proportion that the non-azotized substances ought to bear to the azotized should be determined by the proportion of Carbon and Nitrogen which are eliminated in the excreta of a healthy man in a given period. Now we know from various experiments that about 300 grains of Nitrogen and 4600 grains of Carbon are daily eliminated by the lungs and skin and by the kidneys and bowels; the proportion of the Nitrogen to the Carbon eliminated being, therefore, nearly as 1 : 15. Now, if we compare the composition of bread and of meat, we shall see what is their relative value as aliments, by the proportion which the C holds to the N. According to Payen,* 1000 grains of Bread contain, in round numbers, 300 of Carbon and 10 of Nitrogen; hence to obtain the 300 grains of Nitrogen required by the system, 30,000 grains (or more than 4 lbs.) of Bread must be consumed; but the 4600 grains of Carbon required are

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* "Des Substances Alimentaires," Paris, 1854.

contained in 15,000 grains of Bread; so that to obtain the requisite supply of Nitrogen a quantity of Bread must be consumed containing exactly double the quantity of Carbon required. Hence it is advantageous to add to a Bread diet a small quantity of Cheese or other highly nitrogenous food. Again, in the case of Meat, 1000 grains contain 100 of Carbon and 30 of Nitrogen; therefore to obtain the 4600 grains of Carbon, no less than 6½ lbs. must be consumed, whilst the requisite 300 grains of Nitrogen are contained in 1½ lb. of Meat; consequently three or four times more meat must be consumed to supply the Carbon than is necessary to furnish the Nitrogen. Here then we see again the economy of the mixed diet which is so generally employed by Man, whether in a barbarous or highly-civilized state; and the following table will show how an admixture of bread and meat would require a much less consumption of both, than if either were taken separately:—

	Grains of Carbon.	*Grains of Nitrogen.*
15,440 grains of Bread contain . . .	4,630	154
4,630 ,, Meat contain . . .	463	154
	5,093	308

Thus about 2 lbs. of bread and ¾ lb. of meat are amply sufficient to compensate the daily losses of the system of a healthy man.* Hence we see the immense advantage as to economy of food which a fixed agricultural population possesses over those wandering tribes of hunters which still people a large part both of the Old and New Continents. The *mixed* diet, to which the inclination of Man in temperate climates seems usually to lead him (when circumstances allow that inclination to develope itself freely), appears, moreover, to be fully conformable to the construction of his dental and digestive apparatus, as well as to his instinctive propensities. And whilst on the one hand it may be freely conceded to the advocates of 'Vegetarianism,' that a well-selected vegetable diet is capable of producing (in the greater number of individuals) the highest *physical* development of which they are capable, it may on the other hand be affirmed with equal certainty, that the substitution of a moderate proportion of animal flesh is in no way injurious, whilst, so far as our evidence at present extends, this seems rather to favour the highest *mental* development. If, indeed, we take a comprehensive survey of the conditions of the various races of Man at present inhabiting the earth, we cannot help being struck with his adaptiveness to a great variety of circumstances, as regards climate, mode of life, diet, &c. And we can scarcely avoid the conclusion, that the Creator, by conferring upon him such an adaptiveness, intended to qualify him for subsisting on those articles of diet, whether animal or vegetable, which are most readily attainable in different parts of the globe; and thus to remove the obstacle which a necessary restriction to any one kind of food would have otherwise opposed to his universal diffusion.

46. When the results of Experience, then, are combined with the teachings of Science, they seem to justify the following conclusions.

1. That a due adjustment of the Albuminous, Oleaginous, and Saccharine constituents of the food, to the varying conditions under which Man

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* See Béclard, "Traité Elementaire de Physiologie," p. 570 *et seq.*, 1862.

exists, is of the first importance; whilst the question of the derivation of the first two of these constituents from the Animal or from the Vegetable kingdom, is one of secondary character; each being capable of yielding them in adequate amount, and the only condition requisite being, that the articles of food shall be so selected as to supply the needful quantity. At the same time it will obviously be requisite that differences should be made in the diet, in accordance with climatic and seasonal variations. For when the external temperature is low, an ample supply of oleaginous matter is indicated, and may be advantageously taken in the form of butter, cocoa, fat meat, or maize-bread. On the other hand, during the heat of summer, the more nearly the diet is assimilated to that of the natives of tropical climates, in the substitution of fruits and farinacea for oleaginous articles, the less will be the liability to disordered health in the autumn.*

II. Experience teaches, however, that it is not a matter of entire indifference, whether the Albuminous constituent be drawn from the Animal or from the Vegetable kingdom; for the use of a highly-animalized diet has a tendency to *raise*, and that of a vegetable diet to *lower*, the proportion of red corpuscles in the Blood; whilst, by a due adjustment of the proportion of the two classes of components, the evil effects of the exclusive use of either may be prevented.

III. So, again, Experience teaches what could scarcely have been anticipated theoretically;—namely, that, notwithstanding the power which the living body possesses, of converting saccharine compounds into oleaginous, the ingestion of a certain amount of Oleaginous matter *as such* is necessary, or at least is favourable, to the maintenance of health. We see this provided in large quantity, in the first aliment prepared by nature for the offspring of the Mammalia; it exists largely in the yolk of the egg of all Oviparous animals. And the laborious investigations of Messrs. Lawes & Gilbert † have shown that the amount of fat contained in ordinary butcher's meat of good quality, to which such a high per-centage of nitrogen is usually attributed, is exceedingly great, varying from one-third to one-half of its weight. In the ordinary diet of every nation on the globe,—whether this be animal, vegetable, or mixed,—we find one or more articles of an oleaginous nature; and there is a natural craving for such substances when they are completely withheld, which indicates that they serve some important purpose in the economy. Although this craving is so far affected by climate, that it leads to the largest consumption of oily matter where the extreme of cold has to be endured, it exists with no less intensity even in tropical regions; and we find the Hindoo adding his modicum of 'ghee' (or rancid butter) to the rice which constitutes his staple article of diet, with the same relish that the Esquimaux feels for his massive lumps of blubber.—It does not seem difficult to understand the *rationale* of this fact. For whilst the Adipose and Nervous tissues are the only portions of the Animal fabric into which fatty matter enters in any considerable proportion, yet its presence has an important influence on the assimilation of albuminous matters, and seems essential to every act of tissue formation. We shall hereafter see that it is probably in the Lacteal system, that the two substances are brought into that mutual relation with each other, which these purposes require; and thus it is obvious that, unless a conversion of saccharine into oleaginous matter can take place in the alimentary canal (of which there is no adequate evidence), no true chyle can be formed, except when oleaginous matters have formed part of the food. There is strong and increasing reason to believe, that a deficiency of oleaginous matter, in a state fit for appropriation by the nutritive processes, is a fertile source of diseased action, especially of that of a tuberculous character; and that the habitual use of it in a larger proportion would operate favourably in the prevention of such maladies, as the employment of cod-liver-oil unquestionably does in their cure. A most remarkable example of this is presented by the population of Iceland; which, notwithstanding the concurrence of every one of the circumstances usually considered favourable to the scrofulous diathesis, enjoys a most remarkable immunity from it,—without any other assignable cause than the peculiarly oleaginous character of the diet usually employed.

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* There can be no doubt that a large proportion of the diseases of the digestive apparatus, which are so fatal among European residents in India and other tropical climates, result from the habitual ingestion of a much larger quantity of food, and this especially of a rich and stimulating character, than the system requires. The loss of appetite consequent upon the diminution of the demand for combustive material, is set down to the deleterious influence of the climate; and an attempt is made to neutralize this by artificial provocatives.—So, it seems probable that many of the 'bilious attacks,' which, in this country, are so frequent in early autumn, and which are commonly set down to the account of fruit (although the subjects of them have often abstained entirely from that article), are really the result of the presence of an excess of hydro-carbonaceous matter in the system, consequent upon over-feeding during the summer, and must be looked-upon as the natural means by which it is got rid of.

† "Phil. Trans." 1859, Pt. ii. p. 495.

IV. Another of the results of Experience, of which Science has not yet given a definite *rationale*, is the necessity of employing *fresh vegetables* as an article of Diet; the almost invariable consequence of the entire omission of them, being the development of that peculiar constitutional disorder which is known as *Scurvy*.* That the deficiency of something which fresh vegetables can alone supply, is the essential cause of this disease (its operation being promoted, however, by other conditions, such as absolute deficiency of food, confinement, bad ventilation, depression of spirits, &c.), may now be regarded as a well-established fact; and it is one which ought to have an important influence on our dietetic arrangements. For if the total withdrawal of these articles be productive of such a fearful depravation of the blood as perverts every function to which the blood is subservient, a diminution of them below the standard requisite for the maintenance of health must necessarily involve a depravation similar in kind though less aggravated in degree; and this, if slight, may be expected to manifest itself, not so much in the production of idiopathic disorders, as in favouring any peculiar tendency to disease which may exist in the system, and in preventing or retarding recovery.† The employment of fresh fruits and of green vegetables seems especially indicated, where a general chronic disorder of nutrition indicates a perverted condition of the circulating material; and especially where there is a disposition to chronic inflammation, induration, and ulceration, in different parts of the body.

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* For a full inquiry into this subject, see the "Brit. and For. Med.-Chir. Rev.," vol. ii. p. 439.

† This 'scorbutic tendency' was fully recognized by the past generation of Physicians, who practised in those good old times when potatoes were a luxury and green vegetables in the winter almost unknown, when the middle classes fed upon salted meat during a great part of the year, and when sagacious old women prescribed nettle-tea and scurvy-grass, with a course of lenitive 'spring-physic,' for the 'cleansing of the blood.'

v. Finally, then, a well-arranged dietetic scheme ought to consist of such a combination of the Albuminous, Oleaginous, and Farinaceous constituents, as is most appropriate to the requirements of the system;—a larger measure of the *albuminous* being supplied, when an unusual amount of nervo-muscular exertion is put-forth, and this supply being then most advantageously derived from animal flesh;—a larger measure of the *oleaginous* being required for the sustentation of the heat in a frigid atmosphere, and this being supplied equally well by the Vegetable kingdom as by the Animal;—and a larger proportion of the *farinaceous*, as a substitute for the oleaginous, being most favourable to health under a high atmospheric temperature. An habitual excess in the use of either of these constituents, above what the demands of the system require, tends towards the production of a particular 'diathesis' or constitutional state, which may manifest itself in a great variety of modes. Thus, an excess of the *albuminous* components, such as is only likely to occur when too large a proportion of animal food is employed, undoubtedly favours the *arthritic* diathesis, which seems to consist in the presence of imperfectly-assimilated histogenetic substances and wrongly-metamorphosed products of disintegration, that are not duly eliminated through the kidneys; and this diathesis not only displays itself in gout and gravel, but modifies the course of other diseases. So, again, an excess of the *oleaginous* constituents of the food tends to the production of the *bilious* diathesis, in which, through the insufficient elimination of hydrocarbonaceous matters, the blood becomes charged with the elements of bile. The excess of *farinaceous* matters, moreover, especially when combined with a deficiency of the albuminous (as it too frequently is among those who are obliged by necessity to live chiefly upon a 'poor' vegetable diet), tends to the production of the *rheumatic* diathesis; which seems to consist, like the arthritic, in the mal-assimilation and wrong metamorphosis of the components of the tissues, but to be especially favoured by the presence either of lactic acid, or of some other product of the metamorphosis of the saccharine compounds. And, as already pointed out, the deficiency of oleaginous matters seems to tend to the development of the *scrofulous* diathesis; and that of fruits and fresh vegetables to the production of the *scorbutic*.*

47. The *absolute quantity* of Food required for the maintenance of the

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* It is worthy of remark that in the times when even the wealthy lived during four or five months of the year almost exclusively upon meat, bread, and flour-puddings, and when, therefore, the diet was far too highly-azotized, as well as deficient in fresh vegetables, Arthritic, Calculous, and Scorbutic disorders were much more common than at present. The introduction and universal employment of the potato has unquestionably done much to correct these two tendencies; on the one hand, by diluting the azotized constituents of the food, so that, with the same bulk, a much smaller proportion of these is now introduced; and on the other, by supplying to the blood some element which is essential to the maintenance of its healthy condition. But with the diminution of the Arthritic diathesis, which the experience of our older practitioners, and the medical writings of the last century, indicate as having taken place during that period, there has been an increase in the Rheumatic;—a change which seems to have a close relation to this alteration in diet. And it seems not improbable, too, that this alteration has

Human body in health, varies so much with the age, sex, constitution, and habits of the individual, and with the circumstances in which he may be placed, that it would be absurd to attempt to fix any standard which should apply to every particular case. The appetite is the only sure guide for the supply of the wants of each; but its indications must not be misinterpreted. To eat *when* we are hungry, is an evidently natural disposition; but to eat *as long as* we are hungry, may not always be prudent. Since the feeling of hunger does not depend so much upon the state of fulness or emptiness of the stomach, as upon the condition of the general system, it appears evident that the ingestion of food cannot *at once* produce the effect of dissipating it, though it will do so after a short time; so that, if we eat with undue rapidity, we may continue swallowing food long after we have taken as much as will really be required for the wants of the system; and every superfluous particle is not merely useless, but injurious. Hence, besides its other important ends, the process of thorough mastication is important, as prolonging the meal, and thus giving time to the system to be made acquainted (as it were) that the supply of its wants is in progress; so that its demand may be abated in due time to prevent the ingestion of more than is required. It is very justly remarked by Dr. Beaumont, that the cessation of this demand, rather than the positive sense of satiety, is the proper guide. "There appears to be a sense of perfect intelligence conveyed to the encephalic centre, which, in health, invariably dictates what quantity of aliment (responding to the sense of hunger and its due satisfaction) is naturally required for the purposes of life; and which, if noticed and properly attended to, would prove the most salutary monitor of health, and effectual preventive of disease. It is not the sense of satiety, for this is beyond the point of healthful indulgence, and is Nature's earliest indication of an abuse and overburden of her powers to replenish the system. It occurs immediately previous to this; and may be known by the pleasurable sensations of perfect satisfaction, ease, and quiescence of body and mind. It is when the stomach says, *enough;* and it is distinguished from satiety by the difference of sensations,—the latter saying *too much.*" Every medical man is well aware how generally this rule is transgressed; some persons making a regular practice of eating to repletion; and others paying far too little attention to the preliminary operations, and thus ingesting more than is good for them, even though they may actually leave-off with an appetite.

48. Although no universal law can be laid down for individuals, it is a matter of much practical importance to be able to form a correct *average* estimate. But even this is given somewhat differently by different observers. Dr. Dalton, for instance,* states that the entire quantity of

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also much to do with that diminished power of sustaining active depletory treatment, which, according to the observations of practitioners of long experience, characterizes the present generation as compared with the preceding. But whilst there is a diminished capability of bearing large blood-lettings, violent purgation, &c., there is at the same time such an increased tendency to a favourable termination in many of those diseases for which they were formerly accounted necessary, as should remove all regret at this change of constitution.—On the question of 'Vegetarianism,' the Author may refer to his articles on that subject in the "Brit. and For. Med.-Chir. Rev.," vol. vi. pp. 76 and 399.

* "Physiology," 1861, p. 97.

food required every 24 hours by a man in full health and taking free exercise is, of meat 16 oz. av., bread 19 oz., fat 3½ oz., and of water 52 fl. oz., that is, about 2¼ lbs. of solid food, and rather more than 3 pints of fluid. Vierordt* considers the adult to be well nourished if, with moderate exercise, he receive daily about 4 oz. of dry albumen, 3 oz. of fat, 11¼ oz. of some starchy substance, and about 1 oz. of salt, which gives a proportion of one part of nitrogenous to three and a half parts of non-nitrogenous food. If to this about 6 pints of water, and the oxygen taken up in the act of respiration, which he estimates at 1½ lb., be added, we shall obtain a total of about 1-20th of the weight of the body consumed in 24 hours. It is from the experience afforded by the usual consumption of food by large bodies of men that our data are obtained; and these data are sufficient to enable us to predict with tolerable accuracy what will be required by similar aggregations, though they can afford no guide to the consumption of individuals. We shall first consider the quantity sufficient for men in regular active exercise; and then inquire how far that may be safely reduced, for those who lead a more sedentary life.—The Diet-scale of the British Navy may be advantageously taken as a specimen of what is required for the first class. It is well known that an extraordinary improvement has taken place in the health of seamen during the last 80 years; so that three ships can now be kept afloat, with only the same number of men as were formerly required for two. This is due to the improvement of the quality of the food, in combination with other prophylactic means. At present, it may safely be affirmed that it would not be easy to construct a diet-scale more adapted to answer the required purpose. The health of crews that have been long afloat, and have been exposed to every variety of external conditions, appears to be preserved (at least when they are under the direction of judicious officers) to the full as well as that of persons subject to similar vicissitudes on shore; and there can be no complaint of insufficiency of food, although the allowance cannot be regarded as superfluous. It consists of from 31 to 35½ oz. of *dry* nutritious matter daily; of this, 26 oz. are vegetable, and the rest animal. From the very careful inquiries of Dr. Ed. Smith upon the "weekly dietaries of low-fed populations," it appears that amongst the labouring classes of England health can be maintained when each adult consumes rather more than 5000 (5279) grains of Carbon and 216 grains of Nitrogen daily; whilst the health either altogether fails or becomes very indifferent when the quantity falls to 4542 grains of Carbon and 187 grains of Nitrogen per diem; the proportion of the C to the N in both cases being about as 24½ : 1. However necessary such a supply of nourishment may be to develope the resources of the Human frame to the utmost, it is more than questionable whether this amount of food is obtained by the average population of this or any other country. M. Béclard, indeed,† estimates that in France the proportion of meat or flesh, including game, fish, eggs, milk, cheese, &c., consumed per head does not exceed 2 oz. per diem, whilst he calculates that in England the consumption is nearly 3 oz. per head per diem.—A considerable reduction in this amount is of course admissible, where little bodily exertion is required, and where there is less exposure to low temperatures. In the case of Prisoners, the diet should of course be as spare as possible, consistently with health; but it should be carefully modified, in individual cases, according to several collateral circumstances, such as depression of mind, compulsory labour, previous intemperate habits, and especially the length of confinement. It has been supposed by some, that prisoners require a fuller diet than persons at large; this is probably erroneous; but more variety is certainly desirable, to counteract, as far as possible, the depressing influence of their condition upon the digestive powers. The evil effect of an undue reduction in the supply of food, and of insufficient attention to its quality, has unfortunately been too frequently displayed in our prisons; a notable example of which will be hereafter alluded to (§ 61). A very excellent scale of dietaries adapted to the different conditions of Prison-life, has been issued by the Government on the recommendation of the Inspector of prisons.—The effects of confinement have been well shown in the experience of the Edinburgh House of Refuge, which was first established in 1832, for the reception of beggars during the Cholera, and which has been continued to the present time. The diet was at first a quart of oatmeal porridge for each person, morning and evening; and at dinner 1 oz. of meat, in broth, with 7 oz. of bread, making altogether about 23 oz. of solid food per day. During some months, this diet seemed to answer very well; the people went out fatter than they came in, owing to the diet being better than that to which they had been accustomed; but afterwards a proneness to disease manifested itself in those who had been residents there for a considerable time, and the diet was therefore somewhat increased with good effect. The quantity of animal food was probably here too small; and the total weight might still have been sufficient, if it had been differently apportioned.

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* "Grundriss d. Phys." 1860, p. 192.

† "Phys." p. 592, 1862.

49. The smallest quantity of food upon which life is known to have been supported with vigour, during a prolonged period, is that on which Cornaro states himself to have subsisted; this was no more than 12 oz. a day, chiefly of vegetable matter, with 14 oz. of light wine, for a period of 58 years. There is another well-known case (that of Thomas Wood, the miller of Billericay, reported to the College of Physicians in 1767 by Sir George Baker), in which a remarkable degree of vigour was sustained for upwards of eighteen years, upon no other nutriment than 16 oz. of flour (containing about 14 oz. of *dry* solids) made into a pudding with water, no other liquid of any kind being taken. There are probably few, however,—at least among those whose avocations require much mental or bodily exertion,—who could long persevere in such a diet. Still it is certain that life with a moderate amount of vigour may be preserved for some time, on a very limited allowance of food; this appears from the records of shipwreck and similar disasters. In regard, however, to those who have been stated to fast for a period of months or even years, taking no nutriment, but maintaining an active condition, it may be safely asserted that they were impostors, probably possessing unusual powers of abstinence, which they took means to magnify.

50. Of the quantity which *can* be devoured at one time, this is scarcely the place to speak; since such feats of gluttony only demonstrate the extraordinary capacity which the stomach may be made to attain by continual practice. Many amusing instances are related by Captain Parry in his "Arctic Voyages;" in one case a young Esquimaux, to whom

he had given (for the sake of curiosity) his full tether, devoured in four-and-twenty hours no less than 35 lbs. of various kinds of aliment, including tallow candles. A case has more recently been published of a Hindoo, who can eat a whole sheep at a time; this probably surpasses any other instance on record. The half-breed *voyageurs* of Canada, according to Sir John Franklin, and the wandering Cossacks of Siberia, as testified by Capt. Cochrane, habitually devour a quantity of animal food which would be soon fatal to any one unused to it. The former are spoken of as very discontented, when put on a short allowance of 8 lbs. of meat a day; their usual consumption being from 12 to 20 lbs.—That a much larger quantity of food than that formerly specified, may be habitually taken with perfect freedom from injurious consequences, under a particular system of exercise, &c., appears from the experience of those who are *trained* for feats of strength, pugilistic encounters, &c. The ordinary belief that the Athletic constitution cannot be long maintained, appears to have no real foundation; nor does it appear that any ultimate injury results from the system being persevered-in for some time. That 'trained' men often fall into bad health on the cessation of the plan, is probably owing in part to the intemperance and other bad habits of persons of the class usually subjected to this discipline. The effects of trainers' regimen are hardness and firmness of the muscles, clearness of the skin, capability of bearing continued severe exercise, and a feeling of freedom and lightness (or 'corkiness') in the limbs. During the continuance of the system, it is found that the body recovers with wonderful facility from the effects of injuries; wounds heal very rapidly; cutaneous eruptions usually disappear. Clearness and vigour of mind, also, are stated to be results of this plan.*

51. It is not enough for the healthy support of the body, that the Food ingested should contain an adequate proportion of alimentary constituents; it is important that these should be in a wholesome or undecomposing state. It is a fact very familiar to German Toxicologists, that cheese, bacon, sausages, and other articles, may spontaneously undergo such deleterious alterations, as give rise, when they are employed as food, to all the symptoms of irritant poisoning, which may even pass-on to produce fatal consequences; that such occurrences are very rare in this country, is probably to be attributed to a difference in the mode of preparation. This change does not appear to consist in simple putrescence; for the effects which the cheese-poison, sausage-poison, &c., produce on the animal economy, are far more potent than mere putrescence could occasion; and it is supposed by Liebig to consist in the generation of a peculiar ferment,

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* The method of training employed by Jackson (a celebrated trainer of prize-fighters in modern times), as deduced from his answers to questions put to him by John Bell, was to begin on a clear foundation by an emetic and two or three purges. Beef and mutton, the lean of fat meat being preferred, constituted the principal food; veal, lamb, and pork were said to be less digestible ("the last purges some men"). Fish was said to be a "watery kind of diet:" and is employed by jockeys who wish to reduce weight by sweating. Stale bread was the only vegetable food allowed. The quantity of fluid permitted was 3¼ pints *per diem*; but fermented liquors were strictly forbidden. Two full meals, with a light supper, were usually taken. The quantity of exercise employed was very considerable, and such as few men of ordinary strength could endure.—This account corresponds very much with that which Hunter gave of the North American Indians, when about to set-forth on a long march.

which the stomach is not able to decompose. Similar changes in ordinary flesh-meat seem to be sometimes consequent upon the previous existence of a diseased condition in the animal which furnished it. Thus from Mr. Gamgee's inquiries it appears* that the sale of meat derived from animals which have suffered from the now prevalent diseases, pleuro-pneumonia and typhoid fever, is lamentably common even in the London markets; and it has been well stated† that "although it may be difficult to prove it by actual cases, there can be no doubt that unwholesome meat is one cause amongst many of the debility and cachexies, the poverty of blood and intractable maladies of the poor who flock to the dispensaries and parochial medical officers, and especially of diarrhœa during hot weather." Many instances of this kind have been recorded;‡ and the risk is quite sufficient to justify a strict prohibition of the use of any such article.—That meat which is simply putrescent is to be considered as injurious *per se*, when habitually employed, is scarcely a matter of reasonable doubt. It is true that some nations are in the habit of keeping their meat until it is tainted, having a preference for it in that condition, which seems to have grown out of the supposed necessity for thus employing it; a preference which has its parallel among the epicures in our own country, who consider the *haut goût* essential to the perfection of their venison or woodcock. One of the most remarkable examples of this kind among a civilized people, is furnished by the inhabitants of the Faroe islands; who, according to the Report of Dr. Panum, who has investigated their Sanitary condition, live during a large part of the year upon meat in a state of incipient decomposition, and introduce *rast*, or half-decayed maggotty flesh, fowl, or fish, as a special relish at the end of a meal.§ The result of such a diet is (as might be anticipated) a continual disorder of the digestive organs, manifesting itself especially by diarrhœa, which also complicates the course of other diseases, and even becomes, from its obstinacy and exhausting character, their most serious occurrence. Moreover, the Faroese are peculiarly liable to suffer severely from epidemics, when these are introduced among them. Hence, notwithstanding that the usual rate of mortality is very low (only 1 in 64⅝ annually), it is obvious that there is a certain constitutional condition among them, which peculiarly favours the reception and propagation of zymotic poisons; and it is quite conformable to the principles elsewhere laid down, to attribute this to the habitual introduction of putrescent matter with the food. It is probable, indeed, that if it were not for the active lives of the Färoese, and their habitual exposure to a low external temperature, the direct effects of their diet would be far more prejudicial than they are; but a large part of these are probably neutralized by that activity of respiration which the habits of life of this hardy people induce, much of the noxious matter being decomposed and eliminated by the combustive process. Hence it may well be conceived, that the effects of putrescent food would be much more decidedly manifested amongst individuals dwelling in close, ill-ventilated apartments; and although the same means of comparison do not exist, since there is no part of our town-population habitually subsisting on such a diet as that of the Faroese, yet there is no want of evidence with regard to the injurious effects of even the occasional employment of putrescent food, especially when any zymotic disease is epidemic.*

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* 'Cattle Plague and Diseased Meat.' Letter to Sir George Grey, 1857, quoted in "Med.-Chir. Rev.," 1858.

† In a Report of the Committee of the Metropolitan Associat. of Medical Officers of Health.

‡ See "Ann. d'Hygiène," 1829, ii. p. 267; 1834, ii. 69; also Taylor in "Guy's Hospital Reports," April, 1843.

§ See Dr. Panum's 'Observations on an Epidemic of Measles in the Färoe Islands,' in the "Bibliothek for Læger," 1846; of which an analysis is given in the "Brit. and For. Med.-Chir. Rev.," vol. vii. p. 419.—Dr. Panum says, "During the interval of many months that the flesh, fish, or fowl, is neither fresh, nor yet wind-dried, it is called 'rast,' a word which I can only translate by half-rotten. This appellation it fully deserves from the horrible smell that it sends forth, from its mouldy aspect, and the numerous maggots that swarm upon it. I have seen a boat's crew of eight men eating with great relish the raw flesh of the ca'aing whale, even though it was so decomposed that the smell of it was disagreeable to me even in an open boat, and the bottom of the boat was almost white with the maggots that fell from the decaying mass."

52. That it is Water which constitutes the natural drink of Man, and that no other liquid can supply its place, is apparent from the most cursory glance at its uses in the system; and it is only necessary here to remark, that the purity of the water habitually ingested is a point of extreme importance. A very minute impregnation with lead, for example, is quite sufficient to develope all the symptoms of chronic lead-poisoning, if the use of such water be sufficiently prolonged. In the case of the ex-royal family of France, many of whom suffered in this manner at Claremont,† the amount of lead was only about one grain per gallon; and in a case subsequently published, in which also the symptoms of lead-poisoning were unequivocally developed, the amount was no more than 1-9th of a grain.‡ So, again, an excess of the saline ingredients which appear to be innocuous in small quantities, may produce a marked disorder of the digestive organs, and (through them) of the system generally.§ Moreover, as in the case of food, the presence of a very small amount of putrescent matter is quite sufficient to produce the most pernicious results, when that matter is habitually introduced into the system; and these results, on the one hand, manifest themselves in the production of certain disorders which appear distinctly traceable to the direct action of the poison so introduced; whilst, on the other, they become apparent in the extraordinary augmentation of the liability to attacks of such zymotic diseases as may at the time be prevalent.‖ The

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* Facts of this kind have been abundantly furnished during the visitations of Cholera. See the "Report of the General Board of Health on the Epidemic Cholera of 1848 and 1849," pp. 63, 64.—An instance of a very remarkable kind occurred at Bridgewater, towards the close of that epidemic, as related to the Author by Dr. Brittan. A cargo of spoiled oysters having been brought to the town, and the sale of them having been prohibited on account of their putrescent condition, they were given away to any who would receive them; and several children in a neighbouring school partook of them plentifully. In the course of the following night, all who had eaten of the oysters (so far as Dr. Brittan could ascertain) were attacked with cholera and choleraic diarrhœa, and eleven of the children died the next day.

† See the account of this case, which presents many features of great interest, in the "Dublin Quarterly Journal of Medical Science," vol. vii. p. 415.

‡ See Herapath in "Medical Gazette," Sept. 20, 1850, p. 518.

§ Of this a very instructive case, which occurred at Wolverton, has been published by Mr. Corfe in the "Pharmaceutical Journal," July, 1848.

‖ For ample evidence to this effect, see Dr. Pereira's "Treatise on Food and Diet," pp. 89-91; and the "Report of the General Board of Health on the Epidemic Cholera antity of water daily consumed is about 4 or 5 pounds; and a slight excess, indicative of its formation in the system, is daily eliminated. The ingestion of large quantities has been shown by Mosler* to cause a considerable increase in the discharge of urea and salts in the urine, which appears to be the result of an increased metamorphosis of the albuminous constituents of the blood and tissues. Besides Water, the chief fluids consumed in England are Beer, Tea, and Coffee. Wine is as yet restricted to the upper classes; but large quantities of Spirits, especially of Gin, are taken by the poor. Whiskey is used by the labouring classes of Ireland and Scotland, and Rum is still served out to the Navy. The proportion of Alcohol in Beer varies from 1 to 12 per cent. In Wine from 8-15 per cent. in the light wines of France and Germany, to 25 per cent. in the Spanish wines. Besides Alcohol all Wines contain certain volatile Ethers, and more or less of the Acetic, Tartaric, and Tannic Acids. Sugar and Extractives are also commonly present. The use of *Alcohol*, in combination with water and with organic and saline compounds, in the various forms of 'fermented liquors,' deserves particular notice, on account of the numerous fallacies which are in vogue respecting it.—In the *first* place, it may be safely affirmed that Alcohol cannot answer any one of those important purposes for which the use of Water is required in the system; and that, on the other hand, it tends to antagonize many of those purposes, by its power of precipitating most of the organic compounds, whose solution in water is essential to their appropriation by the living body. *Secondly*, the ingestion of Alcoholic liquors cannot supply anything which is essential to the due nutrition of the system; since we find not only individuals, but whole nations, maintaining the highest vigour and activity, both of body and mind, without ever employing them as an article of diet. *Thirdly*, there is no reason to believe that Alcohol, in any of its forms, can become directly subservient to the Nutrition of the tissues; for it may be certainly affirmed that, in common with non-azotized substances in general, it is incapable of transformation into Albuminous compounds; and there is no sufficient evidence, that even Fatty matters can be generated in the body at its expense.† *Fourthly*, the Alimentary value of Alcohol, if it possess any, consists merely in its power of contributing to the production of heat, by affording a pabulum for the re-

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of 1848 and 1849," pp. 59-63, "Appendix A," p. 14, and "Appendix B," pp. 91-95. —The following very instructive case occurred a few years ago, within the Author's own knowledge. In a certain terrace, in the most aristocratic suburb of a large provincial town, consisting of houses of a superior class, and very favourably situated as regards the access of pure air, an epidemic of gastric fever broke-out, much to the astonishment and dismay of the residents, no such malady having ever been known to prevail in the neighbourhood. It was soon observed, however, that the attacks of the fever were limited (in the first instance at least) to those individuals who were accustomed to use the water of a neighbouring well; those who were supplied from a deep spring at a distance being entirely free. For some little time before this outbreak, a disagreeable taste had been observed in the well-water; and this was subsequently traced to the bursting of a sewer, which had discharged part of its contents into the well. This cause being removed, there has since been no tendency whatever to a recurrence of the effect.

* "Archiv des Vereins. gemeins. Arbeit.," Band iii., 1857, p. 398.

† It is quite true that some persons who consume large quantities of fermented liquors become very fat; but the material for this fat is probably derived in part from the constituents of the food, and in part from the disintegration of the tissues; the hydrocarbonaceous matters in the system being prevented from undergoing the combustive

spiratory process: but the experiments of Duroy, Lallemand, Perrin,* and those of Dr. Ed. Smith,† have shown that some at least of the Alcohol absorbed is discharged unaltered in the secretions of the skin, lungs, and kidneys, whilst the result of the experience of Arctic Voyagers is *most decided* in regard to the comparatively low value of Alcohol as a heat-producing material.‡ *Fifthly*, the operation of Alcohol upon the living body is essentially that of a *stimulus;* increasing for a time, like other stimuli, the vital activity of the body, and especially that of the nervo-muscular apparatus, so that a greater effect may often be produced in a given time under its use, than can be obtained without it; but being followed by a corresponding depression of power, which is the more prolonged and severe, in proportion as the previous excitement has been greater. Still it is certain that Alcohol is not without its value under various corporeal conditions; and the views expressed by Dr. Hammond,§ that its effects, injurious or salutary, are in great measure dependent upon the quantity of food consumed with it, are probably true. When the food is ample in quantity and varied in quality, and the digestion good, Alcohol is unnecessary, exciting the circulation, and tending to produce a plethoric condition of the system;‖ but when the diet is insufficient, or the digestion feeble, the effects of Alcohol, when taken in moderate quantities, seem decidedly beneficial, the body not only ceasing to lose, but actually gaining in weight: the Alcohol either taking the place of the food, or retarding the metamorphosis of the tissues.—The Physiological objections to the habitual use of Alcoholic liquors, rest upon the following grounds. *First*, they are universally admitted to possess a *poisonous* character, when administered in large doses; death being the speedy result, through the suspension of nervous power, which their introduction into the circulation in sufficient quantity is certain to induce. *Secondly*, when habitually used in excessive quantities, universal experience shows that Alcoholic liquors tend to produce a morbid condition of the body at large, and especially of the nervous system; this condition being such as a knowledge of its *modus operandi* on the body would lead the Physiologist to predicate. *Thirdly*, the frequent occurrence of more chronic diseases of the same character, among persons advanced in life, who have habitually made use of Alcoholic liquors in 'moderate' amount, affords a strong probability that they result from a gradual perversion of the nutritive processes, of which that habit is the

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process to which they would otherwise be subject. Much of the fatty deposit in intemperate persons has the character of 'fatty degeneration;' the tendency to which is very marked in persons of this class.

* "Du rôle de l'Alcool et des Anesthétiques dans l'Organisme," 1860.

† "Cyclical Changes."

‡ Dr. Marcet, who has given an excellent account of the long-continued action of stimulants upon the health in his "Chronic Alcoholic Intoxication," 1862, is of opinion that very little of the Alcohol taken by habitual drinkers is really absorbed into the blood; the greater part, after undergoing certain chemical changes, being eliminated through the intestines with the other excreta.

§ "Amer. Journ. of Med. Sciences," Oct. 1856.

‖ According to Dr. Ed. Smith ("Transact. of Roy. Med. Society of London," vol. i., pt. I., p. 1, 1861), Alcohol interferes with Alimentation, diminishes the excretion of Urea and the action of the Skin, and increases the general activity of the Vascular System. Rum increases, but Brandy and Gin lessen the excretion of Carbonic Acid by the lungs.

cause. This perversion manifests itself peculiarly in the tendency to 'fatty degeneration' of the muscular substance of the heart, of the walls of the arteries, of the glandular substance of the kidney and liver, and of many other parts; and thus gives rise to a great variety of forms of disease. *Fourthly*, the special liability of the intemperate to zymotic diseases, seems an indication that the habitual ingestion of Alcoholic liquors tends to prevent the due elimination of the azotized products of the disintegration of the system, and thus to induce a 'fermentible' condition of the blood. *Fifthly*, extended experience has shown, that notwithstanding the temporary augmentation of power which may result from the occasional use of fermented liquors, the capacity for prolonged endurance of mental or bodily labour, and for resisting the extremes of heat and cold, as well as other depressing agencies, is diminished rather than increased by their habitual employment. On these grounds, the Author has felt himself fully justified in the conclusion, that, for Physiological reasons alone, habitual abstinence from Alcoholic liquors is the best rule that can be laid down for the great majority of healthy individuals; the exceptional cases in which any real benefit can be derived from their use, being comparatively few.*

53. The very extensive employment of Tobacco by men of almost every rank in society in this country, and the large consumption of Tea and Coffee by both sexes throughout the community render the study of their effects upon the animal economy particularly interesting, though up to the present time exceedingly few observations have been made. The effects of Tobacco are chiefly due to the absorption of the extremely poisonous liquid Alkaloid Nicotia, which exists in the plant in combination with Citric and Malic Acids, and from its remarkable volatility, is contained in and inhaled with the smoke of the smouldering leaves. Its chemical composition is represented by the formula $C_{10}H_7N$. Dr. Hammond's conclusions (Op. cit.) from his experiments upon the use of Tobacco are, that whilst it only slightly affects the excretion of carbonic acid from the lungs, it diminishes the quantity of fæces, urine, aqueous vapour, and of chlorine, but it increases the amount of uric, phosphoric, and sulphuric acids eliminated by the kidneys,—circumstances which seem to indicate that there is an increase in the interstitial changes taking place in the brain and nervous tissue, of which there are other indubitable signs, as wakefulness, trembling, and nervous excitement. The quantity employed in the experiment was two cigars thrice a day.—These results accord with general experience; and there are few who will not coincide with the moderate tone of Sir B. Brodie's well-known letter to the "Times" on this subject, dated Aug. 27, 1860, in which he observes that when used in moderate quantity, and under circumstances of privation, Tobacco may be not only harmless but absolutely beneficial, by soothing and tranquillizing the nervous system, allaying hunger and the uneasy feelings produced by mental and bodily exhaustion; but that in too many instances it is only a bad habit, producing a greater or less degree of derangement of the nervous system, and indisposing to both mental and bodily exertion. Tea and Coffee, though derived from different classes of the Vegetable kingdom,

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* See his "Physiology of Temperance and Total Abstinence;" also the important Treatise on "Alcoholismus Chronicus" by Dr. Huss of Stockholm, of which an abstract is given in the "Brit. and For. Med.-Chir. Rev.," vols. vii. and ix.

appear to contain nearly the same organic constituents, but in different proportions, as shown in the following analysis:—

		100 *Parts of Tea contain*		100 *Parts of Coffee contain*
Water		5		12
Theine		3		1·75
Caseine		15		13
Gum		18		9
Sugar		3		6·5
Tannic Acid		26·25		4
Aromatic Oil		0·75		0.002
Fibre		20		35·048
Fat	Chlorophyll Wax Resin	4	Olein Palmitin	12
Mineral Substances		5		6·7

In making "Tea" and "Coffee," the Theine, Gum, Sugar, and Tannic Acids are chiefly extracted, the Casein, unless a little soda be added to the water, being undissolved. It is a singular circumstance that the Alkaloid contained in Tea and Coffee, as well as that in Maté, the shrub used for tea in Paraguay, should have the same chemical composition ($C_{16}H_{10}N_4O_4$ + 2 Aq.). Strong decoctions of both fluids counteract the tendency to sleep, but Voit found in an extended series of experiments upon a dog, that Coffee possessed little or no influence upon the general nutrition of the body in that animal.* J. Lehmann,† however, arrived at the conclusion that Coffee, and Bocker ‡ that Tea, exercised an important influence in retarding the waste of the tissues in Man; and Dr. Ed. Smith § considers that whilst the employment of Coffee diminishes the action of the skin, it increases that of the bowels.

2. *Of Hunger and Thirst;—Starvation.*

54. The want of solid Aliment, arising from the demands of the system for the materials requisite for the growth and maintenance of the body, and for the combustive process, is indicated by the sensation of Hunger; and that of liquid, by Thirst. The former of these sensations is referred to the stomach, and the latter to the fauces; but although certain conditions of these parts may be the immediate cause of the sensations in question, they are really indicative of the requirements of the system at large. For the intensity of the feeling bears no constant relation to the amount of solid or liquid aliment in the stomach; whilst, on the other hand, it does correspond with the excess of demand in the system, over the supply afforded by the blood; and it is caused to abate by the introduction of the requisite material into the circulating fluid, even though this be not accomplished in the usual manner by the ingestion of food or drink into the stomach.

55. That the sense of Hunger, however, is *immediately* dependent upon some condition of the Stomach, seems to follow from the fact, that it may be temporarily alleviated by introducing into the digestive cavity

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* See Henle and Meissner, "Bericht," 1860, p. 402.

† "Liebig's Annalen," lxxxvii. p. 205.

‡ "Archiv d. Vereins f. gemeins." 1853.

§ "Dublin Med. Journ.," 1860, p. 59.

matter which is not alimentary. Of the precise nature of that condition, we have no certain knowledge. It is easy to prove that many of the causes which have been assigned for the sensation, are but little, if at all, concerned in producing it. Thus, mere emptiness of the Stomach cannot occasion it; since, if the previous meal have been ample, the food passes from its cavity some time before the uneasy feeling is renewed; and this emptiness may continue (in certain disordered states of the system) for many hours or even days, without a return of desire for food. Besides, the stomach may be filled with food, and yet Hunger may be intensely felt, if, from disease of the pylorus or any other cause, there be an obstacle to the passage of the aliment into the intestine, and to the completion of the processes of chylification and absorption, so that the system needs that which the digestive apparatus is unable to provide for it. Again, the sense of Hunger cannot be due, as some have supposed, to the action of the gastric fluid upon the coats of the stomach themselves; since this fluid is not poured into the stomach, except when its production is stimulated by the irritation of the secreting follicles.—It may, perhaps, be a more probable supposition, that there is a certain condition of the Capillary circulation in the Stomach, which is preparatory to the secretion, and which is excited by the influence of the Sympathetic nerves, that communicate (as it were) the wants of the general system. This condition may be easily imagined to be the proximate cause of the sensation of hunger, by acting on the nervous centres.* When food is introduced into the stomach, the act of secretion is directly excited; the capillary vessels are gradually unloaded; and the immediate cause of the impression on the nervous system is withdrawn.† By the conversion of the alimentary matter into materials fit for the nutrition of the system, the remote demand also is satisfied; and thus it is, that the condition of the stomach just referred-to, is permanently relieved by the ingestion of substances that can serve as food. But if the ingested matter be not of a kind capable of solution and assimilation, or the digestive apparatus cannot effect its preparation, the feeling of hunger is only temporarily relieved, and soon returns in greater force than before.—The theory here given seems reconcilable with all that has been said of the conditions of the sense of Hunger; and particularly with what is known of the effect produced upon it by nervous impressions, which have a peculiar influence upon the capillary circulation. It also corresponds exactly with what we know of the influence of the nervous system, and of mental impressions, upon other secretions (CHAP. XV.).

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* It was maintained by Brachet, that the senses of Hunger and Satiety are annihilated by section of the Pneumogastric nerves, which, if true, would strongly confirm the view that the immediate source of these senses lies in the condition of the Stomach. But the researches of other experimenters, particularly those of Dr. John Reid ("Edinb. Med. and Surg. Journ." April, 1839, and "Physiological, Anatomical, and Pathological Researches," pp. 234-239), and of Bernard (Lecture xxi., "Med. T. and Gaz." July, 1860), do not confirm this view; for they seem to show that after the immediate effect of the operation has subsided, animals take food with no less avidity than previously. It appears, however, from Dr. Reid's observations, as well as from those of Valentin, that the sense of Satiety is more dependent upon the continuity of these nerves, than is that of Hunger; for animals on which the section of the Pneumogastric has been performed, do not seem to know when they have had enough, but continue to gorge themselves with food long after the stomach has been adequately filled.

† These views seem to be confirmed by the observations of M. Bernard on the condition of the gastric follicles during the intervals of their functional activity.

56. The sense of Hunger, like other sensations, may not be taken cognizance of by the Mind, if its attention be strongly directed towards other objects; of this fact, almost every one engaged in active operations, whether mental or bodily, is occasionally conscious. The nocturnal student, who takes a light and early evening meal, and, after devoting himself to his pursuits for several hours uninterruptedly, retires to rest with a wearied head and an empty stomach, but without the least sensation of hunger, is frequently prevented from sleeping by an indescribable feeling of restlessness and *deficiency;* and the introduction of a small quantity of food into the stomach will almost instantaneously allay this, and procure comfortable rest. Many persons, again, who desire to take active exercise before breakfast, are prevented from doing so by the lassitude and even faintness which it induces,—the bodily exercise increasing the demand for food, whilst it draws-off the attention from the sensation of hunger.

57. The conditions of the sense of Thirst appear to be very analogous to those of hunger. This sense is not referred, however, to the stomach, but to the fauces. It is probably even more immediately connected with the state of the general system, than that of hunger; for the immediate relief afforded by the introduction of liquid into the stomach, is fully accounted-for by the instantaneous absorption of the fluid into the veins, which is well known to take place when there is a demand for it. This demand is increased with almost equal rapidity, by an excess in the amount of the fluid excretions; and it may be satisfied, or at least alleviated, without the introduction of water into the stomach, this having been one of the results observed after the use of saline injections into the veins in cases of Asiatic Cholera, as well as after immersion in a warm bath in cases of extreme dysphagia. Thirst may also be produced, however, by the impression made by peculiar kinds of food or drink upon the walls of the alimentary canal; thus salted or highly-spiced meat, fermented liquors when too little diluted, and other similarly irritating agents, excite thirst; the purpose of which is obviously to cause ingestion of fluid by which they may be diluted.

58. The results of an entire deficiency of Food, or of its supply in a measure inadequate for the wants of the system, constitute the phenomena of *Inanition* or *Starvation.* These have been experimentally studied by M. Chossat* on Birds and Mammals; and the information thence gained leads us to a better comprehension of what is (unfortunately) too frequently exhibited in the Human subject.—The following were the general symptoms noted by M. Chossat. The animals usually remain calm during the first half or two-thirds of the period; but they then become more or less agitated; and this state continues as long as their temperature remains elevated. On the last day of life, however, whilst the temperature rapidly falls, this restlessness ceases, and gives place to a state of stupor. The animal, when set at liberty, sometimes looks round with astonishment, without attempting to fly; and sometimes closes the eyes, as if in a state of sleep. Gradually the extremities become cold, and the limbs so weak as no longer to be able to sustain the animal in a standing posture; it falls over on one side, and remains in any position in which

* "Recherches Expérimentales sur l'Inanition," Paris, 1843.

it may be placed, without attempting to move. The respiration becomes slower and slower; the general weakness increases, and the insensibility becomes more profound; the pupil dilates; and life becomes extinct, sometimes in a calm and tranquil manner, sometimes after convulsive actions producing opisthotonic rigidity of the body. After the first day, in which the fæces contain the residue of the food previously taken, their amount is very small; and they seem to consist principally of grass-green biliary matter. Towards the close of life, they contain a much larger quantity of water, even when none has been ingested by the animal; and include much saline matter in addition to the biliary.—The average loss of weight in the warm-blooded animals experimented-on by M. Chossat, between the commencement of the period of Inanition and its termination by death, was 40 per cent; but he met with a considerable variation in the extremes, which seemed to depend chiefly on the amount of fat previously accumulated in the body; those animals losing most weight, in which the fat had been most abundant, which were also those that lived the longest.* Taking 40 per cent as the mean, M. Chossat obtained the following curious results, as regards the relative diminution of the several tissues and organs of the body; those which lost *more* than the mean, being distinguished from those which lost *less*.

Parts which lose *more* than 40 per cent.		Parts which lose *less* than 40 per cent.	
Fat	93·3	Muscular coat of stomach	39·7
Blood	75·0	Pharynx and œsophagus	34·2
Spleen	71·4	Skin	33·3
Pancreas	64·1	Kidneys	31·9
Liver	52·0	Respiratory apparatus	22·2
Heart	44·8	Osseous system	16·7
Intestines	42·4	Eyes	10·0
Muscles of Locomotion	42·3	Nervous system	1·9

The points most worthy of note in the above table, are the almost complete removal of the *fat*, and the reduction of the *blood* to three-fourths its normal amount; whilst the *nervous system* undergoes scarcely any loss. It would seem, in fact, as if the supervention of death was coincident with the consumption of all the disposable combustive material; and that up to that point, the whole remaining energy of nutrition is concentrated upon the nervous system. And it will be shown hereafter that there is adequate ground for considering death by *starvation* as really death by *cold;* since the temperature of the body is maintained with little diminution until the fat is thus consumed, and then rapidly falls, unless it be kept up by heat externally applied.—As might be expected from the comparative rapidity of interstitial change at the earlier periods of life, it was found by Chossat that the diurnal loss was much the most rapid in young animals, and that the duration of their lives when deprived of food was consequently far less than that of adults. He further ascertained that the results of *insufficient* alimentation were in the end the same as those of entire deprivation of food; the total amount of loss being almost exactly identical, but its rate being less, so that a longer time was required to produce it. He did not find that much influence was exerted on the duration of life, by permitting or withdrawing the supply of water; but Scheffer* found in a dog wholly deprived of water the loss in weight of the different organs was nearly the same as in deprivation of solid food, except in the case of the adipose tissue, which does not materially diminish. All the tissues become much drier; the skin, tendons, muscles, intestines and blood, containing from 4-11 per cent more solid residue than in health. The brain, however, and glandular organs were much less affected. And it appears also that in Man death supervenes much earlier when liquid as well as solid aliment is withheld; and the indifference observed by Chossat in the case of Birds is probably due to the fact, that they ordinarily drink very sparingly, and eliminate very little water in their various excretions.

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* There is a well-known case of a fat pig, which was buried in its sty for 160 days, under thirty feet of the chalk of Dover cliff; and which was dug out alive at the end of that time, reduced in weight from 160 lbs. to 40 lbs., or no less than 75 per cent. ("Trans. of Linn. Soc.," vol. xi. p. 411). The extraordinary prolongation of life in this case may be attributed to the retention of the *heat* of the body by the non-conducting power of the chalk, and to the retention of its *moisture* by the saturation of the air in its immediate vicinity, and restriction of its movements.

59. The most prominent symptoms of Starvation, as they have been noted in the Human subject, are as follows:—In the first place, severe pain in the epigastrium, which is relieved on pressure; this subsides after a day or two, but is succeeded by a feeling of weakness and 'sinking' in the same region; and an insatiable thirst supervenes, which, if water be withheld, thenceforth becomes the most distressing symptom. The countenance becomes pale and cadaverous; the eyes acquire a peculiar wild and glistening stare; and general emaciation soon manifests itself. The body then exhales a peculiar fœtor, and the skin is covered with a brownish, dirty-looking, and offensive secretion. The bodily strength rapidly declines; the sufferer totters in walking, his voice becomes weak, and he is incapable of the least exertion. The mental powers exhibit a similar prostration; at first there is usually a state of stupidity, which gradually increases to imbecility, so that it is difficult to induce the sufferer to make any effort for his own benefit; and on this a state of maniacal delirium frequently supervenes. Life terminates either in the mode described in Chossat's observations, or, as occasionally happens, in a convulsive paroxysm.†—On post-mortem examination, the condition of the body is found to be such as the results of Chossat's observations would indicate; namely, extreme general emaciation and disappearance of fat, diminution in the bulk of the principal viscera, and almost complete bloodlessness, save in the brain, which still receives its usual supply. It is specially worthy of note, that the coats of the small intestines are peculiarly thinned, so that they become almost transparent; and that the gall-bladder is almost invariably turgid with bile, the cadaveric exudation of which tinges the surrounding parts. And further, the body rapidly passes into decomposition.

60. Now it is peculiarly worthy of note, that the deficient supply of new histogenetic materials appears to check the elimination and removal of those which have become effete; for in no other way can we account

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* Ludwig, "Physiologie," 1861, vol. ii. p. 683.

† See Rostan in "Diction. de Médecine," art. 'Abstinence;' and Dr. Donovan's account of the Irish famine of 1847 in the "Dublin Medical Press," Feb., 1848; also a paper by Martin, "Med. T. and Gaz.," April, 1861.

for that tendency to putrescence, which is so remarkably manifested during life in the fœtid exhalation and in the peculiar secretion from the skin, and which is shown after death in the rapidity with which putrefaction supervenes. Moreover, towards the close of many exhausting diseases, the fatal termination of which is really due to a chronic inanition, it frequently happens that a 'colliquative diarrhœa' comes on, which must be considered as a manifestation of the general disintegration that is making progress even during life.—Now referring to the conditions hereafter to be enumerated, as those which favour the operation of zymotic poisons in the body, it is obvious that no state could be more liable to it than this; since we have not merely that general depression of the vital powers, which is a predisposing cause of almost any kind of malady, and pre-eminently so of zymotic diseases; but also the presence of a large amount of disintegrating matter in the blood and general system, which forms the most favourable nidus possible for the reception and multiplication of such poisons. And thus it happens that pestilential diseases most certainly follow in the wake of a famine, and carry off a far greater number than perish from actual starvation.

61. Another class of phenomena, however, results from such a deficiency of alimentation as is not adequate to produce the results just described; provided this deficiency be prolonged for a considerable length of time, and especially if it be conjoined with other unfavourable conditions. Of this, a remarkable example was presented at the Milbank Penitentiary in 1823. The prisoners confined in this establishment, who had previously received an allowance of from 31 to 33 oz. of dry nutriment daily, had this allowance suddenly reduced to 21 oz., animal food being almost entirely excluded from the diet scale. They were at the same time subjected to a low grade of temperature, and to considerable exertion; and were confined within the walls of a prison situated in the midst of a marsh which is below the level of the adjoining river. The prison had been previously considered healthy; but in the course of a few months, the health of a large proportion of the inmates began to give way. The first symptoms were loss of colour, and diminution of flesh and strength; subsequently diarrhœa, dysentery, and scurvy; and lastly adynamic fevers, or headache, vertigo, convulsions, maniacal delirium, apoplexy, &c. The smallest loss of blood produced syncope, which was frequently fatal: and after death, ulceration of the mucous lining of the alimentary canal was very commonly found. Out of 860 prisoners, no fewer than 437, or 52 per cent, were thus affected. The influence of concurrent conditions, especially of previous confinement, was here remarkably shown; for those were found to be most liable to disease, who had been in prison the longest. That the reduction of the allowance of food, however, was the main source of the epidemic, was proved by the two following facts:—the prisoners employed in the kitchen, who had 8 oz. of bread additional per day, were not attacked, except three who had only been there a few days: and after the epidemic had spread to a great extent, it was found that the addition of 8 oz. to the daily allowance of vegetable food, and ½ oz. to the animal, greatly facilitated the operation of the remedies which were used for the restoration of health.*

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* See Dr. Latham "On the Diseases in the Millbank Penitentiary," 1824. A similar

62. It is a curious effect of insufficient nutriment, as shown by the inquiries of Chossat (Op. cit.), that it produces an incapability of digesting even the small amount consumed. He found that when turtle-doves were supplied with limited quantities of corn, but with water at discretion, the whole amount of food taken was scarcely ever actually digested; a part of it being rejected by vomiting, or passing-off by diarrhœa, or accumulating in the crop. It seems as if the vital powers were not sufficient to furnish the requisite supply of gastric fluid, when the body began to be enfeebled by insufficient nutrition; or perhaps we might well say, the materials of the gastric fluid were wanting.—Hence the loathing of food, which is often manifested by those who have been subjected to the influence of an insufficient diet scale in our prisons and poor-houses, and which has been set down to caprice or obstinacy, and punished accordingly, may be actually a proof of the deficiency of the supply, which we might expect to have been voraciously devoured, if really less than the wants of the system require.

63. It is extremely important that the Medical Practitioner should be aware, that many of the phenomena above described may be induced by the adoption of a system of too-rigid abstinence in the treatment of various diseases; and that they have been frequently confounded with the symptoms of the malady itself, and have led to an entirely erroneous method of treating it. "Many cases," says Dr. Copland,* "have occurred to me in practice, where the antiphlogistic regimen, which had been too rigidly pursued, was itself the cause of the very symptoms which it was employed to remove. Of these symptoms, the affection of the head and delirium are the most remarkable, and the most readily mistaken for an actual disease requiring abstinence for its removal."—The experience of those especially, who are largely engaged in consulting practice, must have furnished numerous illustrations of the above statement. Dr. Copland mentions the following. "A professional man had been seized with fever, for which a too-rigid abstinence was enforced, not only during its continuance, but also during convalescence. Delirium had been present at the height of the fever, and recurred when the patient was convalescent. A physician of eminence in maniacal cases was called to him, and recommended that he should be removed to a private asylum. Before this was carried into effect, I was requested to see him. A different treatment and regimen, with a gradual increase of nourishment, were adopted; and he was well in a few days, and within a fortnight returned to his professional avocations."

64. The time during which life can be supported under entire abstinence from food or drink, is usually stated to vary from eight to ten days;† the period may be greatly prolonged, however, by the occasional use of

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example of the effects of prolonged insufficiency of diet was furnished at the Maison Centrale of Nîmes, for a highly instructive account of which by M. Boileau-Castelnau, chief physician to the 'Maison Centrale,' see "Ann. d'Hygiène Publ." Janv., 1849.

* "Dictionary of Practical Medicine," vol. i. p. 26.

† There seems adequate evidence, that a state which may be characterized as one of *Syncope*,—the animal functions being entirely suspended, and the organic functions being reduced to an extremely low ebb,—may be prolonged for many days, or even weeks, provided the temperature of the body be not too much reduced. This class of facts, however, will be more appropriately considered hereafter (CHAP. XIX.).

water, and still more by a very small supply of food: or, even, it would seem by a moist condition of the surrounding atmosphere, which obstructs the exhalation of liquid from the body. Thus Foderé mentions that some workmen were extricated alive, after fourteen days' confinement in a cold damp vault, in which they had been buried under a ruin. Dr. Sloan has given an account* of the case of a healthy man æt. 65, who was found alive after having been shut-up in a coal-mine for twenty-three days, during the first ten of which he was able to procure and swallow a small quantity of foul water; he was in a state of extreme exhaustion, and died three days afterwards, notwithstanding the attempts made to recover him. —It would seem as if certain conditions of the Nervous system, especially those attended with peculiar emotional excitement, are favourable to the prolongation of life under such circumstances. Thus, in a case recorded by Dr. Willan, of a young gentleman who starved himself under the influence of a religious delusion, life was prolonged for sixty days; during the whole of which time, nothing else was taken than a little orange-juice. In a somewhat similar case which occurred under the Author's notice, in the person of a young French lady, more than fifteen days elapsed between the time that she ceased to eat regularly, and the time of her being compelled to receive nourishment; during this period she took a good deal of exercise, and her strength seemed to suffer but little, although she swallowed solid food only once, and then in small quantity. Again, in certain states of the system commonly known as 'hysterical,' there is frequently a very remarkable disposition for abstinence, and power of sustaining it. It may be well to remark that, under such circumstances, the continual persuasions of anxious friends are very injurious to the patient; whose return to her usual state will probably take place the earlier, the more completely she is left to herself.

3. *Movements of the Alimentary Canal.*

65. The motions by which Food is conveyed to the *Mouth* and introduced into its cavity, constituting the acts of *Prehension* and *Ingestion*, are ordinarily considered to be *voluntary*, at least in the adult; and it is indubitable that the Will has entire control over them. Nevertheless, they belong to the class of 'secondarily automatic' movements; and like those of locomotion, may be kept-up when the will is in abeyance, by the suggesting and guiding influence of sensations, thus being performed under the same essential conditions as the purely 'consensual' or 'sensori-motor' actions.† The necessity of 'guiding sensations' for their performance is made evident by one of Sir C. Bell's experiments, the wrong interpretation of whose results originally led him to an erroneous view of the functions of the Fifth pair of nerves. He found that an Ass, in which the infra-orbital branch of this nerve had been divided, made no attempt to pick-up oats with its lip, although the animal saw them, bent-down its

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* "Medical Gazette," vol. xvii. p. 389.

† This, the Author thinks, will be conformable to the experience of most of his readers; who will find, if they analyze their own consciousness, that they continue to eat while their whole *attention* is given to some abstract train of thought, or to some external object. But a remarkable case will be cited hereafter (CHAP. XI.), which fully confirms the view here advanced; the movements, not merely of the lips and jaws, but those by which food was conveyed to the mouth, having been carried-on *automatically*, when once (so to speak) the spring was touched by which they were set in action.

head with the obvious purpose of ingesting them, and brought its lip into absolute contact with them; hence he concluded that the power of *motion* was destroyed in the lip, when it was in reality only the *guiding sensation* that was deficient, the motor power being supplied by the Facial nerve or Portio dura.

66. The food thus introduced into the mouth, is subjected (unless it be already in a state which needs no further reduction) to the process of *Mastication.* This is evidently an operation of great importance, in preparing the substances to be afterwards operated-on, for the action of their solvent; and it exactly corresponds with the trituration to which the Chemist would submit any solid matter, that he might present it in the most advantageous form to a digestive menstruum. The complete disintegration of the alimentary matter is, therefore, of great consequence; and, if imperfectly effected, the subsequent processes are liable to derangement. Such derangement we continually meet with; for there is not, perhaps, a more frequent source of Dyspepsia than imperfect mastication, whether resulting from the haste with which food is swallowed, or from the want of the instruments proper for the reducing operation. The mechanical disintegration of the food is manifestly aided by Insalivation; but the admixture of Saliva also exerts, as we shall hereafter see, a very marked influence on the chemical composition of certain of its constituents.—The movements of Mastication, still more than those already adverted-to, although under the complete control of the Will, and originally dependent upon it for their excitation, come at last to be of so *habitual* a character, that they continue when the direct influence of the will is withdrawn, the influence of the guiding 'sensation,' however, being essential to their performance. Every one is conscious that the act of mastication may be performed as well, when the mind is attentively dwelling on some other object, as when directed to *it;* but, in the former case, we are rather apt to go on chewing and rechewing what is already fit to be swallowed, simply because the will does not exert itself to check the action, and to carry the food backwards within the reach of the muscles of deglutition. This conveyance of food backwards to the fauces is a distinctly voluntary act; and it is necessary that it should be guided by the sensation, which there results from the contact it induces. If the surface of the pharynx were as destitute of sensation, as is the lower part of the œsophagus, we should not know when we had done what was necessary to excite its muscles to operation.—The muscles concerned in the Mastication of food are nearly all supplied by the third branch of the Fifth pair, a large proportion of which is well known to have a motor character. Many of these muscles, especially those of the cheeks, are also supplied by the Facial nerve; and yet, if the former be paralyzed, the latter cannot stimulate them to the necessary combined actions. Hence we see that the movements are of an associated character, their due performance being dependent on the part of the nervous centres, from which the motor influence originates. If the Fifth pair, on the other hand, be uninjured, whilst the Portio Dura is paralyzed, the movements of Mastication are performed without difficulty; whilst those connected in any way with the Respiratory function, or with Expression, are paralyzed. If, again, the sensory portion of the Fifth pair be paralyzed,

the act of Mastication is very imperfectly performed, even though the motor power be not in the least impaired; for the muscles cannot be made to perform the requisite associated movements without the guidance of sensations; so that the morsel lodges between the teeth and the cheek, or beneath the tongue, and can with difficulty be kept in the appropriate position.

67. When the reduction of the food in the mouth has been sufficiently accomplished, it is carried into the *Pharynx*, and is thence propelled down the œsophagus into the stomach, by a set of associated movements, which taken together, constitute the act of *Deglutition*. These movements were first described in detail by Magendie; but his account requires some modification, through the more recent observations of Dzondi,* Budge,† Bidder,‡ Czermak, and Schuh.§ The first stage in the process is the carrying back of the food until it has passed the anterior palatine arch; this is effected by the contraction of the mylohyoid,‖ the longitudinal and transverse muscles of the tongue, which together render the tongue shorter and thicker, pressing it against the roof of the mouth, whilst the styloglossi draw it somewhat backward: these movements are purely voluntary. The second act now commences, during which the entrance of food into the nasal cavities and trachea is most jealously guarded against, by certain reflex actions which have only been clearly recognised since the introduction of the laryngoscope by Czermak. During this act the tongue is carried still farther backwards, the larynx rises, so as to be covered by the epiglottis, which is at the same time somewhat depressed, and placed horizontally, so that its upper border touches the posterior wall of the pharynx. The cushion at the base of the epiglottis becomes applied to the arytenoid cartilages, and the vocal cords, both true and false, are closely approximated; a triple protection against the entrance of the food into the trachea being thus afforded. Coincidently with these movements, the lower border of the velum palati becomes applied to the walls of the pharynx, and the muscles of the posterior palatine arch contract in such a manner, as to cause the sides of the arch to approach each other like a pair of curtains, so that the passage from the fauces into the posterior nares is nearly closed by them; and to the cleft between the approximated sides, the uvula is applied like a valve. A sort of inclined plane, directed obliquely downwards and backwards, is thus formed; and the morsel slides along it into the pharynx, which is brought-up to receive it. Though some of these acts may be performed voluntarily, the combination of the whole is automatic.¶ The *third* stage of the process, the propulsion of the food down the œsophagus, then commences. This is accomplished, in the upper part, by means of the constrictors of the

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* See Prof. Muller's "Elements of Physiology" (translated by Dr. Baly), p. 501.

† "Phys.," 1860, p. 157.

‡ "Neue Beobachtungen," Dorpat, 1838.

§ "On the Laryngoscope," Canstatt, 1858.

‖ Tourtual, "Neue Untersuchungen," Leip. 1846.

¶ The observations of Schuh (Canstatt, 1858) upon the movements of the soft palate during deglutition seem to show that this part is somewhat more active during the second stage than it was described to be by Dzondi. He had an opportunity of observing them in a woman, the left side of whose face had been removed by an operation. When the patient drank, the soft palate raised itself above the horizontal line, as soon as the glass was approximated to her lips. It remained in this position whilst the fluid pharynx; and in the lower, by the muscular coat of the œsophagus itself. When the morsels are small, and are mixed with much fluid, the undulating movements from-above-downwards succeed each other very rapidly, as may be well observed in Horses whilst drinking; large morsels, however, are frequently some time in making their way down. Each portion of food and drink is included in the contractile walls, which are closely applied to it during the whole of its transit. The gurgling sound, which is observed when drink is poured down the throat of a person in *articulo mortis*, is due to the want of this contraction. The whole of the third stage is completely involuntary.—At the point where the œsophagus enters the stomach, the 'cardiac orifice' of the latter, there is a sort of sphincter, which is usually closed, but which opens when sufficient pressure is made on it by accumulated food, closing again, when this has passed, so as to retain it in the stomach.

68. The purely *automatic* nature of the act of Deglutition is shown by the fact, that no attempt on our part will succeed in performing it really *voluntarily*. In order to excite it, we must apply some stimulus to the fauces. A very small particle of solid matter, or a little fluid (saliva, for instance), or the contact of the back of the tongue itself, will be sufficient; but without either of these, *we cannot swallow at will.* Nor can we restrain the tendency, when it is thus excited by a stimulus; every one knows how irresistible it is, when the fauces are touched in any unusual manner; and it is equally beyond the direct control of the will, in the ordinary process of eating,—voluntary as we commonly regard this. Moreover, this action is performed, like that of respiration, when the power of the will is suspended, as in profound sleep, or in apoplexy affecting only the brain; and it does not seem to be at all affected by the entire removal of the brain, in an animal that can sustain the shock of the operation; being readily excitable, on stimulating the fauces, so long as the nervous structure retains its functions. This has been experimentally proved by Dr. M. Hall; and it harmonizes with the natural experiment sometimes brought under our notice in the case of an anencephalous infant, in which the power of swallowing seems as vigorous as in the perfect one. But, if the 'nervous circle' be destroyed, either by division of the trunks, or by injury of any kind to the portion of the nervous centres connected with them, the action can no longer be performed; and thus we see that, when the effects of apoplexy are extending themselves from the brain to the spinal cord, whilst the respiration becomes stertorous, the power of Deglutition is lost, and then respiration also speedily ceases.

69. Our knowledge of the nerves specially concerned in this action, is principally due to the very careful and well-conducted experiments of Dr. J. Reid.* From a careful examination of the actions of deglutition, and of the influence of various nerves upon them, Dr. Reid drew the following

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was being sucked in; but as soon as swallowing commenced it very suddenly descended, so as to press the fluid into the œsophagus. It then again elevated itself with even greater tension, and again descended. In swallowing solid food the same sudden ascent and descent of the Velum upon the deglutition of each morsel was observable.

* "Edinb. Med. and Surg. Journ.," vol. xlix.; and "Physiological, Anatomical, and Pathological Researches," CHAP. IV.

conclusions:—The *excitor impressions* are conveyed to the Medulla Oblongata chiefly through the Glosso-pharyngeal, but also along the branches of the Fifth pair distributed upon the fauces, and probably along the superior laryngeal branches of the Pneumogastric distributed upon the pharynx. The *motor influence* passes chiefly along the pharyngeal branches of the Pneumogastric, which are probably originally derived from the Spinal Accessory; along the branches of the Hypoglossal, distributed to the muscles of the tongue, and to the sterno-hyoid, sterno-thyroid, and thyro-hyoid muscles; along the motor filaments of the Recurrent laryngeals; along some of the branches of the Fifth, supplying the elevator muscles of the lower jaw; along the branches of the Facial, ramifying upon the digastric and stylo-hyoid muscles and upon those of the lower part of the face; and probably along some of the branches of the Cervical plexus, which unite themselves to the descendens noni. It was further observed by Dr. Reid, that the stylo-pharyngeus muscle is usually thrown into contraction, when the roots of the Glosso-pharyngeal nerve are irritated; and as this has been also noticed by Mayo, Volkmann, and others, we are probably to consider the Glosso-pharyngeal as a motor nerve, in so far as that muscle is concerned.*

70. When the food has been propelled downwards by the Pharyngeal muscles, so far as their action extends, its further progress through the *Œsophagus* is effected by a kind of peristaltic contraction of the muscular coat of the tube itself. This movement is not, however, due *only* to the *direct* stimulus of the muscular fibre by the pressure of the food, as it seems to be in the lower part of the alimentary canal; for Dr. J. Reid has found, by repeated experiment, that the continuity of the œsophageal branches of the Pneumogastric with the Medulla Oblongata is necessary for the rapid propulsion of the food; so that it can scarcely be doubted, that an impression made upon the mucous surface of the œsophagus, conveyed by the afferent fibres of these nerves to their ganglionic centre, and reflected downwards along the motor fibres, is the real cause of the muscular contraction. If the Pneumogastric be divided in the rabbit, on each side, above the œsophageal plexus, but below the pharyngeal branches, and the animal be then fed, it is found that the food is delayed in the œsophagus, from spasmodic contraction of the cardiac sphincter, which becomes greatly distended. Further, if the lower extremity of the Pneumogastric be irritated, distinct contractions are seen in the œsophageal tube, proceeding from above downwards, and extending over the cardiac extremity of the stomach.—We have here, then, a distinct case of *reflex action, without sensation*, occurring as one of the *regular associated movements* in the natural condition of the animal body; and it is very interesting to find this following upon a reflex action *with* sensation (that of the pharynx), and preceding a movement which is but slightly connected with the Spinal Cord (that of the lower part of the alimentary canal). The use of sensation in the former case has been already shown. The muscular fibres of the Œsophagus are *also* excitable, though usually in a less degree, by *direct* stimulation; for it appears that, in some animals

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* Op. cit., pp. 258-260.—It seems not improbable that the discrepant results obtained by different experimenters on this point, are partly to be explained by differences in the distribution of the nerves in the several species of animals operated-on.

(the Dog, for example), section of the pneumogastric does not produce that check to the propulsion of the food, which it occasions in the Rabbit; and even in the Rabbit, as Dr. M. Hall has remarked,* the simple contractility of the muscular fibre occasions a distinct peristaltic movement along the tube, after its nerves have been divided; causing it to discharge its contents when cut across. Such a movement, indeed, seems to take place in something of a rhythmical manner (that is, at short and tolerably regular intervals,) whilst a meal is being swallowed; but as the stomach becomes full, the intervals are longer, and the wave-like contractions less frequent. The reopening of the cardiac orifice, on pressure from *within* (which is usually resisted by the sphincter, as in the acts of defecation, parturition, &c.), is one of the first of that series of reversed actions which constitutes the act of *Vomiting;* and this is accompanied by a reversed peristaltic action of the œsophagus. The independence of these actions, one of another, and their relation to a common cause, is remarkably shown by the fact, that when vomiting takes place as a consequence of the injection of tartar-emetic into the veins, the reversed peristaltic action of the œsophagus is performed even after its separation from the stomach.

71. The food, which, thus propelled along the œsophagus, enters the *Stomach* through its cardiac orifice in successive waves, is immediately subjected to a peculiar peristaltic movement, which has for its object to produce the thorough intermixture of the gastric fluid with the alimentary mass, and to separate the portion which has been sufficiently reduced, from the remainder. The fasciculi composing the muscular wall of the Human stomach, are so disposed as to lessen its diameter in every direction; and whilst the cavity is empty, they are uniformly contracted, so as to reduce the organ to its smallest dimensions. When food is introduced, the contraction of the parietes as a whole still continues, to such a degree as to make them closely apply themselves to its surface; but the contraction of the individual fasciculi alternates with relaxation, in such a manner as to induce a great variety of motions in this organ, sometimes transversely, and at other times longitudinally. "These motions," remarks Dr. Beaumont, who has enjoyed a peculiar opportunity of observing them,† "not only produce a constant disturbance or *churning* of the contents of the stomach, but they compel them at the same time to revolve about the interior from point to point, and from one extremity to the other." In addition to these movements, there is a constant agitation of the stomach, produced by the respiratory muscles. The nature of these, and indeed of all peristaltic movements, has been stated by Dr. Brinton ‡ to resemble very closely those produced by the descent of a perforated piston in a closed tube containing fluid, for here there would be peripheral currents passing in the same direction as the piston, and a central current flowing in the opposite direction, through the perforation in the piston. The direction which the particles of food take, as described by Dr. Beaumont, corresponds very fairly with this view. He says:—"The bolus as

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* "Third Memoir on the Nervous System," § 201.

† See the "Case of Alexis St. Martin, with Observations and Experiments by Dr. Beaumont," republished in this country by Dr. Andrew Combe.—This patient had a large fistulous orifice in his stomach, remaining after a wound which had laid-open the cavity; but his general health had been completely restored.

‡ "Cyclop. Anat. and Phys.," vol. v. pp. 313 and 345.

it enters the cardia, turns to the left, passes the aperture, descends into the splenic extremity, and follows the great curvature towards the pyloric end. It then returns, in the course of the smaller curvature (or as Dr. Brinton supposes, through the axis of the stomach), and makes its appearance again at the aperture in its descent into the great curvature, to perform similar revolutions. These revolutions are completed in from one to three minutes. They are probably induced, in a great measure, by the circular or transverse muscles of the stomach. They are slower at first, than after chymification has considerably advanced;" at which time also there is an increased impulse towards the pylorus. It is probable that, from the very commencement of chymification, until the organ becomes empty, portions of chyme are continually passing into the duodenum; for the bulk of the alimentary mass progressively diminishes, and this the more rapidly as the process is nearer its completion. The accelerated expulsion appears to be effected by a peculiar action of the transverse muscles; and especially of that portion of them, which surrounds the stomach at about four inches from its pyloric extremity. This band is so forcibly contracted in the latter part of the digestive process, that it almost separates the two portions of the stomach into a sort of hour-glass form; and Dr. Beaumont states that, when he attempted to introduce a long thermometer-tube into the pyloric portion of the stomach, the bulb was at first gently resisted, then allowed to pass, and then grasped by the muscular parietes beyond, so as to be drawn-in: whence it appears that the contraction has for its object, to resist the passage of solid bodies into the pyloric extremity of the stomach, at this stage of digestion, whilst the matter which has been reduced to the fluid form is pumped-away (as it were) by the action of that portion of the viscus. These peculiar motions continue, until the stomach is perfectly empty, and not a particle of food or of chyme remains; and when they are nearly brought to a close, the contraction of the pyloric orifice also gives-way, to an extent sufficient to allow not only the undigested residue of the food, but also large solid bodies that may have been swallowed (such as coins and the like), to pass into the intestinal canal.

72. With regard to the degree in which these movements of the Stomach, whose share in the Digestive operation is so important, are dependent upon the Spinal cord, and are consequently of a 'reflex' nature, it is difficult to speak with certainty, owing to the contradictory results obtained by different experimenters. These contradictions, however, seem partly due to a diversity in the nature of the animals experimented-on, and partly to a difference in the stage of the digestive process at which the observations were made. It seems to be well established by the researches of Reid, Valentin, and others,* that distinct movements may be excited in the stomach of the Rabbit, if distended with food, by irritating the Pneumogastric soon after the death of the animal; these movements appear to commence from the cardiac orifice, and then to spread

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* See Dr. Reid's "Physiological, Anatomical, and Pathological Researches," chap. v.; Valentin, "De Functionibus Nervorum Cerebralium," &c., chap. xi.; also Longet, "Anat. et Physiol. du Systême Nerveux," tom. i. p. 323; and "Physiologie," vol. i. p. 234, 1861; and Bischoff in "Muller's Archiv," 1843. Pincus, "Exp. de vi Nervi Vagi," Wratislaw, 1856; Hartung, "Ueber die Nervi Vagi," Giessen, 1858; Schiff, "Physiologie," 1859, p. 420; Bernard, "Med. Times and Gaz.," 1860, vol. ii. p. 1; Ravitsch, "Muller's Archiv," 1861, p. 779.

themselves in a sort of peristaltic manner along the walls of the stomach: but no such movements can be excited if the stomach be empty. When the Pneumogastrics are divided in the neck, the cardiac orifice of the stomach becomes spasmodically contracted*—a condition which, after lasting for about thirty-six hours, generally passes off. If previously to that period the animal be allowed to eat, the food accumulates in the lower part of the œsophagus, and death results from suffocation. The contraction of the cardiac sphincter appears, therefore, to be governed by other nerves than the Pneumogastric, and in all probability the Sympathetic determines its closure; but there is abundant evidence to show that the peristaltic movements of the stomach are chiefly governed by the Pneumogastrics, and are materially impaired when these are divided. Yet after their section if small portions of food be introduced into the stomach, these can still be propelled downwards, either as Ludwig† and Schiff‡ suppose, from the reflex action of the ganglia of the Sympathetic, or from the contractions of the muscular fibres produced by direct irritation. The moderate excitement of pleasurable emotions is favourable to the operation of digestion; not only by giving firmness and regularity to the action of the heart, and thence promoting the circulation of the blood and the increase of the gastric secretion; but also in all probability by imparting firmness and regularity to the muscular contractions of the stomach.

73. Much discussion has taken place upon the question, how far contraction of the parietes of the Stomach itself actively participates in the operation of *Vomiting*; and many experiments have been made to determine the facts of the case. Some, like Magendie, have gone so far as to affirm that the stomach is entirely passive; grounding this inference upon the fact experimentally ascertained, that when the stomach was removed, and a bladder was substituted for it, this was emptied of its contents by the compression of the parietes of the abdomen, when tartar-emetic was injected into the veins. But this fact by no means disproves the active co-operation of the stomach; and judging from the analogy of the uterus, bladder, and rectum,—whose muscular walls are all actively concerned in the expulsion of their contents, though that expulsion is in great part due to the contraction of the abdominal muscles,—we should be led to concur with the common opinion, of which our own sensations during the act would indicate the correctness. And this opinion has been confirmed by observation of a case,§ in which, the abdominal parietes having been accidentally laid-open in the human subject, and the stomach having wholly protruded itself, it was seen to contract itself repeatedly and forcibly, during the space of half an hour, until by its own efforts it had expelled all its contents except gases.‖ Contraction of the Pylorus, which, according to Budge,¶ takes place with great energy, and (as already mentioned), relaxation of the cardiac sphincter, are essential to the act of vomiting;

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[*] Bernard, "Med. Times and Gaz.," 1860, vol. ii. p. 1.

[†] "Physiologie," p. 614.

[‡] "Untersuchungen zur Naturlehre," viii. p. 323.

[§] Lepine, in "Bullet. de l'Acad. Roy. de Médecine," 1844.

[‖] Dr. Brinton thinks it improbable that antiperistaltic movements ever occur, such an effect as vomiting being always produced by an active peristalsis occasioning an energetic axial recurrent stream. But it appears certain that such movements have been actually witnessed, both in Man and Animals (Ludwig, vol. ii. p. 617; Busch, "Virchow's Archiv," vol. xiv. p. 140; Todd and Bowman, vol. ii. p. 236). They are described as being intermittent, and ceasing during sleep.

[¶] Budge, "Lehrbuch der Physiologie," 1862, p. 179.

and unless the latter takes place, all the other movements will be in vain: for its fibres, when contracted, can resist the combined force of all the expulsor muscles. There can be little doubt that the violent but fruitless efforts at vomiting which we occasionally witness (two or three such efforts frequently preceding the effectual one), are prevented from emptying the stomach by the obstinacy with which the cardiac sphincter is kept closed; just as the expiratory effort which assists in emptying the stomach, is prevented, by the firmness with which the glottis is held shut, from expelling the contents of the chest. It is not true, as was formerly supposed, that the diaphragm actively co-operates in the effort of vomiting; for, as was first pointed-out by Dr. M. Hall,* this effort, like those of defæcation, urination, and parturition, is essentially performed by the muscles of expiration; with this difference, however, that the diaphragm, instead of being *passive*, is fixed, and supplies a firm surface against which the stomach is pressed. In this, as in the other cases just referred-to, the expulsive effort is preceded by a deep inspiration, after which the glottis is spasmodically closed during its whole continuance.—The immediate causes of vomiting may be reduced to three different categories. 1st. The contact of irritating substances with the mucous membrane of the stomach itself; these, however, cannot act by *direct* stimulation upon more than its own muscular coat; and their operation upon the associated muscles must take place by *reflexion*, through the 'nervous circle' furnished by the pneumogastrics† and the motor nerves of expiration. 2nd. Irritations applied to other parts of the body, likewise operating by *simply-reflex* transmission; as in the vomiting which is consequent upon the strangulation of a hernia, or the passage of a renal calculus; or in that which is excited by the injection of tartar-emetic or emetin into the circulating current, where these substances probably produce their characteristic effect by their operation on the nervous centres. 3rd. Impressions received through the *sensorial* centres, which may be either sensational or emotional, but which do not operate unless they are *felt*. In this mode seems to be excited the vomiting that is induced by tickling the fauces, which first gives rise to the sensation of nausea; as well as the vomiting consequent upon disgusting sights, odours, or tastes, and upon those peculiar internal sensations which are preliminary to 'sea-sickness.' The *recollection* of these sensations, conjoined with the emotional state which they originally excited, may itself become an efficient cause of the action, at least in individuals of peculiarly irritable stomachs or of highly sensitive nervous systems; for this plays downwards upon the sensorial centres, in such a manner as to excite in them the same condition as that which was originally produced through the medium of the sensory nerve when the object was actually present. (See CHAP. XI., Sect. 3.)

74. The passage of the Chyme, or product of the gastric digestion, through the pyloric orifice, into the commencement of the *Intestinal tube*, is at first slow; but when the digestive process is nearly completed, it is transmitted in much larger quantities. The pyloric orifice, like the cardiac, is furnished with a sphincter muscle; but how far its contractions

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* "Quarterly Journal of Science," vol. xxv. p. 388 *et seq.*

† Remak observed that, after section of one Pneumogastric, irritation of the centric extremity produced powerful contractions of the Abdominal Muscles, and induced vomiting (Schiff, "Phys.," p. 420), a fact which has also been corroborated by Budge ("Physiolog." 1862, p. 180) and Waller, "Froriep's Tagesbericht," 1851, p. 315).

are dependent upon 'reflex action,' has not yet been ascertained. The ingested matter, which undergoes further changes of a very important character within this portion of the canal, is gradually propelled onwards by the peristaltic contractions of its walls, and these are excited by the contact, either of the products of digestion, or of the secretions poured-in by the various glands that discharge their products into the intestinal tube.* In its progress along the small intestines, the nutritious portion of the ingested matter is gradually taken-up by the blood-vessels and absorbents, and the residue, combined with excrementitious matters separated from the blood, begins to assume the fæcal character. A further absorption takes place during the passage of the fæcal matter through the large intestines, and thus by the time it reaches the rectum, it has acquired a considerable degree of consistency.—The ordinary Peristaltic movements of the Intestinal canal may, to some extent, be referred to reflex action through the chain of Nerves and nervous ganglia, one layer of which has been shown by Meissner to exist in the submucous areolar tissue, and another, by Auerbach, between the circular and longitudinal layers of muscular tissue of the small intestines, and on the outside of the longitudinal layer in the large intestine.† They may, however, be excited by irritation of more distant sympathetic centres, as of the solar plexus,‡ and of the Sympathetic Ganglia of the Neck.§ Indeed, the experiments of Valentin, who, more than any other Physiologist, has succeeded in obtaining positive results of this kind, indicate that the motor influence does not originate in the Sympathetic Ganglia, but is primarily derived from the Spinal cord.‖ The following are his general results, so far as they apply to this part of the subject.—The lower part of the Œsophagus in the neck is made to contract peristaltically from above downwards, by irritation of the roots of the first three cervical Spinal nerves, and of the cervical portion of the Sympathetic, through which last the former evidently operate. The thoracic portion of the œsophagus is made to contract, by irritation of the lowest Sympathetic ganglion of the neck, and of the higher thoracic ganglia, and also of the roots of the lower cervical Spinal nerves.—Muscular contractions of the Stomach are produced in the rabbit, by irritation of the roots of the 4th, 5th, 6th, and 7th cervical Spinal nerves, and of the 1st thoracic, so that a distinct furrow is evident between the cardiac and pyloric portions of the viscus, and the lower the nerve irritated, the nearer to the pylorus do the contractions extend. Irritation of the first thoracic ganglion of the Sympathetic produces the same effect.—Contractions of the Intestinal tube, varying in place according to the part of the Spinal cord experimented-on, may be excited by irritation of the roots of the dorsal, lumbar, and sacral nerves, and of the trigeminus, and similar effects are produced by irritation of the lower part of the thoracic portion, of the lumbar, and of the sacral portions of the Sympathetic,—also of the splanchnic, and of the gastric plexuses.* Pflüger was led from his observations† to consider that irritation of the Splanchnic Nerves may, according to circumstances, check the movements of the small intestines if they be already present, or occasion them if the muscles are at rest.

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* The Bile seems to have an important share in producing this effect, since, when the ductus choledochus is tied, constipation always occurs. The purgative action of Mercurials seems to depend in great part upon the increase of the hepatic and other secretions which it induces.

† Auerbach, "Canstatt's Jahresbericht," 1862, p. 174, Manz, "Die Nerven und Ganglien des Saugethierdarms," 1859, Krause, "Studien des Phys. Instit. zu Breslau," 1863, p. 31. "Unters. ub. einig Ursach. der peristalt. Beweg. des Darmcanals."

‡ Ludwig, "Physiologie," vol. ii. 1861, p. 616.

§ Valentin, "De Functionibus Nervorum Cerebralium et Nervi Sympathici, book ii. chap. ii.

‖ Ibid.

75. From these facts it is evident, that the movements of the Intestinal tube may be *influenced by* the Spinal Cord; and that what is commonly termed the Sympathetic nerve, is the channel of that influence, by the fibres which it derives from the Spinal system. But it by no means thence follows, that the ordinary peristaltic actions of the muscles in question are *dependent* on a stimulus reflected through the spinal cord, rather than on one directly applied to themselves. It is clear that, although these movements are of the first importance to the welfare of the system, such means of sustaining them are feeble, compared to those which we find provided for the maintenance of the distinctly-reflex actions of deglutition, respiration, &c. And the fact that they are capable of being at all times more easily excited by stimuli applied to the muscles, than by any kind of irritation applied to their nerves,—taken in connection with the fact that the muscles not only remain irritable, but will execute regular peristaltic contractions, for a long time after any such contractions can be excited through their nerves,—seems a very strong indication that though the nervous influence is the chief, yet that it is *not* the only agent in calling these movements into play. And as we well know that the peristaltic movements are affected by particular states of mind, or by conditions of the bodily system, the connection just traced satisfactorily accounts for this, and is itself sufficiently explained. The rapidity with which the food traverses the intestinal tube is subject to great variations. In a case of artificial anus which opened into the upper part of the jejunum, reported by Dr. Busch,‡ the first portions of food usually appeared in from 22 to 30 minutes after ingestion. Whilst in another case reported by Dr. Braune,§ in which the artificial anus communicated with the intestine a few inches above the ileo-colic valve; the first appearance of the food presented itself three hours after ingestion, and the last about six hours after, so that we may consider the time occupied by the food in traversing the small intestine to be about 2½ hours. The food having traversed the small intestine enters the cæcum by an aperture guarded by a valve (the Iliocæcal), whose lateral position is clearly a provision for preventing the whole weight of the Fæces as the remains of the food here begin to be called by which it might be forced back, from resting upon it. The Fæces in their ascent are lodged in the sacculi of the Colon, by which they are supported during the intervals of the peristaltic action of the Muscular Coat. In their course through the descending colon, they

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* Budge and Schiff, moreover, in experiments on Cats, obtained intestinal movements on direct irritation of the Corpora Striata, Optic Thalami, Corpora Quadrigemina, Pons Varolii, Medulla Oblongata, and the Peduncles of the Brain and Cerebellum. Longet, however ("Phys." 1861, vol. i. p. 149), on repeating these experiments in Dogs and Rabbits was unable to arrive at any definite result. See Budge ("Lehrbuch der Physiologie," 1862, p. 785), and Schiff, private communication to Longet ("Physiologie," p. 149). Krause is of opinion that the peristaltic movements of the intestines are chiefly the result of the circulation of blood containing a deficiency of oxygen. (See "Studien der Physiolog. Instituts zu Breslau," 1863, p. 44.)

† "Ueber das Hemmungs Nerven System, fur die peristalt. Beweg. der Gedärumen." Berlin, 1856.

‡ "Virchow's Archiv," vol. xiv. p. 140.

§ "Archives Générales de Méd.," 1861, p. 610.

pass through its remarkable sigmoid flexure, by which they are prevented from directly pressing against the Anal orifice. As regards the movements of the large intestine, they differ from those of the small intestine in that they cannot, according to Pflüger, be checked by irritation of the Splanchnic Nerves.

76. On examining the outlet by which the fæces are voided, we find that it is placed, like the entrance, under the guardianship of the Spinal Cord; subject, however, to some control on the part of the Will. In the lowest animals, the act of discharging excrementitious matter is probably as involuntary as are the acts immediately concerned in the introduction of nutriment; and it is performed as often as there is anything to be got rid of. In the higher classes, however, such discharges are much less frequent; and reservoirs are provided, in which the excrementitious matter may accumulate in the intervals. The associated movements required to empty these, are completely involuntary in their character; and are excited by the quantity, or stimulating quality, of the contents of the reservoir. But, had volition no control over them, great inconvenience would ensue; hence sensation is excited by the same stimulus which produces the movements, in order that, by arousing the will, the otherwise involuntary motions may be restrained and directed.—There can be little doubt, from the experiments of Dr. M. Hall, as well as from other considerations, that the associated movements by which the contents of the rectum and bladder are discharged, correspond much with those of Respiration; being in their own nature excito-motor, but being capable of a certain degree of voluntary restraint and assistance. The act of Defæcation (as of Urination) chiefly depends upon the combined contraction of the abdominal muscles, similar to that which is concerned in the expiratory movement; but, the glottis being closed so as to prevent the upward motion of the diaphragm, their force acts only on the contents of the abdominal cavity; and so long as the sphincter of the cardia remains closed, it must press downwards upon the walls of the rectum and bladder,—the contents of the one or the other of these cavities, or of both, being expelled, according to the condition of their respective sphincters. These actions are doubtless assisted by the contraction of the walls of the rectum and bladder themselves; for we sometimes find their agency sufficient to expel the contents of the cavities, when there is a total paralysis of the ordinary expulsors, provided that the sphincters be at the same time sufficiently relaxed. This is more especially the case, when their power is augmented by increased nutrition. For example, in many cases of disease or injury of the Spinal Cord, the bladder ceases to expel its contents, through the interruption of the circle of reflex action; but after a time, the necessity for drawing off the urine by the catheter is found to exist no longer, the fluid being constantly expelled as soon as it has accumulated in small quantities. In such cases, the mucous coat is found after death to be thickened and inflamed; and the muscular coat to be greatly increased in strength, and contracted upon itself. It would seem, then, that the abnormal irritability of the mucous membrane, and the increased nutrition of the muscular substance which appears consequent upon it, enable the latter to expel the urine without the assistance of the ordinary expulsors.

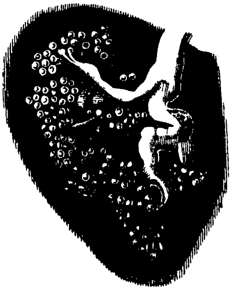
77. On the other hand, the sphincters which antagonize the expellent action, are usually maintained in a state of moderate contraction, so as to afford a constant check to the egress of the contents of the cavities; and

this condition has been fully proved by Dr. M. Hall, to result from their connection with the Spinal Cord, ceasing completely when this is interrupted. But the sphincters are certainly in part controlled by the Will, and are made to act in obedience to the warning given by sensation; and this voluntary power is frequently destroyed by injuries of the Brain, whilst the Spinal Cord remains able to perform all its own functions, so that discharge of the urine and fæces occurs.—In their state of moderate excitement, the expulsors and the sphincters may be regarded as balancing one another, so far as their reflex action is concerned; the latter having rather the predominance, so as to restrain the operation of the former. But, when the quantity or quality of the contents of the cavity gives an excessive stimulus to the former, their action predominates, unless the Will be put in force to strengthen the resistance of the sphincter; this we are frequently experiencing, sometimes to our great discomfort. On the other hand, if the stimulus be deficient, the will must aid the expulsors, in order to overcome that resistance which is due to the reflex contraction of the sphincters; of this also we may convince ourselves, when a sense of propriety, or a prospective regard to convenience, occasions us to evacuate the contents of the rectum or bladder without a natural call to do so.

4. *Of the Changes which the Food undergoes, during its passage along the Alimentary Canal.*

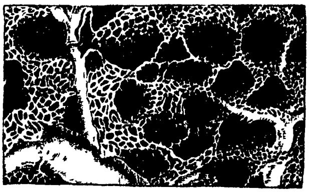
78. The object of the Digestive process, as already pointed-out, is to reduce the Alimentary matters to a condition in which they can be introduced by Absorption into the Circulating system. This reduction is partly effected, as we have seen, by Mechanical means; but it is chiefly due to the Chemical agencies which are brought to bear upon the ingested substances, during their transit through the mouth, the stomach, and the upper portion of the intestinal tube. The first of these is exerted by the *Salivary* fluid, which is incorporated with the food in the act of mastication, and of which a large quantity descends with it to the stomach. For the secretion of this fluid, it will be remembered that three pairs of glands of considerable size are provided; namely, the parotid, the sublingual, and the submaxillary. But in addition to these, a very important part of the fluid is furnished by the lingual and palatine glands, and by the numerous follicular glands lodged in and beneath the buccal mucous membrane. The Salivary glands are constructed upon that follicular type, of which a characteristic example is presented in the glands of Brunner (Fig. 17); their ultimate follicles (Fig. 8) are very minute (their average diameter being about 1-1200th part of an inch), and are closely surrounded by a plexus of capillary blood-vessels (Fig. 9). Their development commences

FIG. 8.



Lobule of *Parotid Gland* of a new-born infant, injected with mercury. Magnified 50 diameters.

FIG. 9.



Capillary Network around the follicles of the *Parotid Gland.*

from a simple canal, sending off bud-like processes, which opens from the mouth, and lies amidst a cellular blastema; and as their evolution advances, the large parent-cells of this blastema form communications with the gland-canal, which is at the same time extending its ramifications, and remain as the terminal follicles of these.

79. Numerous researches have shown, that the characters of the fluids poured forth respectively from the three principal glands are by no means identical; and that the buccal mucus has a very important share in the operations of that mixed product, which constitutes the ordinary Saliva. The specific gravity of this fluid is usually (according to Lehmann) from 1004 to 1006; but he states that it may rise to 1008 or 1009, or may sink to 1002, without any indication of coexisting disease: according to Jacubowitsch, however, its average specific gravity is no higher than 1002·6. These variations appear partly referable to the amount of solids and liquids ingested, and to the amount of the secretion previously poured-out; but they may be partly attributed to a difference in the proportions of the fluids poured into the mouth by the several glands which secrete them. The Saliva is found to contain a few epithelial scales thrown off by the buccal mucous membrane, and a small number of minute corpuscles proceeding chiefly from the lingual and tonsillitic glands, which perform curious spontaneous and Amœba-like movements.* Its reaction is always alkaline in health; but the degree of alkalinity varies, being greatest during and after meals, and least after prolonged fasting, when the fluid is almost neutral. The following are some of the chief analyses of this fluid that have been made:—

In 1000 *Parts.*	*Simon.*†	*Berzelius.* ‡	*Frerichs.*§	*Jacubowitsch*‖	*Harley.*¶
Water	991·22	992·9	994·10	995·16	993·331
Solid Residue	8 78	7·1	5·90	4·84	6·69
Ptyalin	—	2·9	—	—	
Ptyalin with some Alcoli Extract	4·37	—	1·41	—	
Soluble Organic Matter (Ptyalin)	—	—	—	1·34	Organic Matters. 3·91
Mucus, epithelium	1·40	1·4	2·13	1·62	
Fat	—	—	0·07	—	
Fat and cholesterine	0·32	—	—	—	
Water-extract, with Salts	2·45	—	—	—	
Alcoholic-extract, with Lactates	—	0·9	—	—	
Sulpho-cyanide of Potassium	—	—	0·10	0·06	
Salts	—	1·9	2·19	1·82	Inorganic Matters. 2·78
Water	991·22	992·9	994·10	995·16	
	1000·	1000·	1000·	1000·	1000·

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* Brücke, "Sitzungsbericht d. Wiener Akad.," Bd. xlv.

† T. Simon, "Animal Chemistry," Syd. Soc. Edit., vol. ii. p. 4.

‡ From "Donders' Phys.," p. 188, 1859.

§ See "Canstatt's Jahresbericht," 1850, p. 136; and "Wagner's Handwörterbuch," Band iii., Art. 'Verdauung.'

‖ Inaugural Dissertation, "De Salivâ," Dorpati, 1848; see also Bidder and Schmidt, "Die Verdauungssaefte und der Stoffwechsel," 1852.

¶ "Brit. and For. Med.-Chir. Rev." 1860, p. 207.

The substance to which the designation of *ptyalin* is given, is that on whose presence the peculiar properties of the Saliva appear to depend; and it seems, as regards its chemical nature, to be an albuminous compound, in such a state of change, however, that it acts the part of a 'ferment.'* Sulphocyanide of Potassium, considered by Bernard† to be only occasionally present, and attributed by some to the presence of carious teeth, and by others conceived to have been mistaken for Nicotine, the essential oil of Tobacco, has been found by Harley to be a constant constituent of the Saliva in persons possessing perfectly sound teeth, and not addicted to smoking. Its use may possibly be that suggested by Kletzinsky‡ to prevent the formation of fungoid spores between, and in the cavities of the teeth. In a medico-legal point of view, the existence of a sulphocyanide in the saliva has a special importance; since, if in a state of sufficient concentration, it causes the saliva to exhibit the same blood-red colour, when treated with a per-salt of iron, as that which is produced by meconic acid. (The difference between the two, however, is easily made apparent, by adding a solution of perchloride of mercury; for this causes the colour produced by the sulphocyanide to disappear, whilst it has no action on that which is due to the presence of meconic acid.) To determine the nature of the differences in the composition and physical characters of the secretion of the several salivary glands, Bernard§ inserted tubes into their ducts, and found, on placing a few drops of vinegar on the tongue of a dog, that the submaxillary saliva was immediately secreted, speedily followed by that from the parotid, and at a later period by that from the sublingual. The parotidean saliva was clear and watery, containing only 0·47 per cent of solid residue in the Dog, and 0·76 in the Horse (Lehmann). The fluid discharged by the sublingual gland was thick and viscid, whilst that of the submaxillary was intermediate in this respect to the others. Hence Bernard was led to suggest that the submaxillary gland ministers to the sense of taste, whilst the parotid is connected with mastication, and the sublingual with deglutition.‖ The Salts, according to the analyses of Schmidt, consist chiefly of Chlorides of Potassium and Sodium, Phosphate of Soda (to which the alkaline reaction of the saliva appears to be due), Earthy Phosphates, and Oxide of Iron. Bernard has shown that various salts, after their introduction directly or indirectly into the Blood, rapidly make their appearance in the saliva; this is particularly the case with Iodide of Potassium, which can often, though not always (Harley), be detected in the saliva long before its appearance in the urine. The Tartar which collects upon the teeth, and the salivary concretions which occasionally obstruct the ducts, consist chiefly of the earthy phosphates held together by about 20 per cent of animal matter. The fluids which are secreted by the three principal glands appear (from the experiments to be presently cited) to have very different degrees of efficacy, in producing that chemical change in the food which it is the peculiar attribute of this secretion to exert.—Of the quantity of Saliva which is secreted daily, it is impossible to form an exact estimate, since it varies greatly with the character of the food ingested, and the frequency with which that food is taken; the secreting process being, indeed, almost suspended when the masticating muscles and tongue are completely at rest, unless excited by a nervous stimulus. The taste, the sight, or even the idea, of savoury food, is sufficient to cause a flow of saliva, especially after a long fast: but it is by the masticatory movements that this flow is chiefly promoted, so that the amount poured-forth will in a great degree depend upon the duration of these movements,—this, again, being governed by the degree in which the food requires mechanical reduction. It is calculated by MM. Bidder and Schmidt, that the average in Man is at about 3½ pounds daily; but Harley, with greater probability, estimates it at from 1 to 2 lbs. The influence of the kind of food upon the quantity secreted was well shown by Lassaigne,* who found on abstracting the Bolus of food, as it passed down the Œsophagus in Horses, that 100 parts of green stalks were mingled with 49 parts of saliva, the same quantity of oats and barley with from 113 to 186 parts, and of dry hay with 406 parts of saliva. Dr. Dalton, however, did not observe such difference in Man,† since 10 parts of fresh cooked meat gained 48 per cent, whilst dry wheaten bread did not gain more than 55 per cent of its weight after thorough mastication.

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* The following, according to Prof. Lehmann ("Physiological Chemistry," Cavendish Society's Ed., vol. ii. p. 15), are the distinctive chemical characters of Ptyalin.—Being held in solution by an alkali, the addition of a little acetic acid throws down a flocculent precipitate, which readily dissolves in an excess of the acid. When boiled with hydrochlorate of ammonia or sulphate of magnesia, the alkaline solution of ptyalin becomes very turbid; it is precipitated by tannic acid, bichloride of mercury, and basic acetate of lead; but not by alum, sulphate of copper, &c. When pure it is colourless and gelatinous, with a slight acid reaction. The acetic acid solution is strongly precipitated on the addition of ferrocyanide of potassium; and when boiled with nitric acid, it yields a yellow solution. By these reactions it is shown that ptyalin closely resembles both albumen and casein, without being identical with either of them.

† "Leçons," 1859, t. ii. p. 243.

‡ "Heller's Archiv," 1833, p. 39.

§ "Leçons," 11, 12, 13, vol. ii. 1859; and Lectures, "Med. Times and Gaz." 1860.

‖ This idea of M. Bernard's was confirmed by the following experiments. He made an opening into the œsophagus of a Horse, from which he drew the alimentary bolus as it descended; and on weighing it, he found that by the imbibition of saliva it had increased *eleven fold.* He next tied Wharton's duct, and found that the animal required 41 minutes to masticate what had previously required only 9 minutes; and the mass, when withdrawn from the œsophagus, was covered with mucus and a glutinous fluid, the interior being dry and friable, and the whole increased in weight only *three and a half* times.—An interesting fact in Comparative Anatomy, which fully confirms the

80. Besides the preparation of the food for the ulterior changes which it has to undergo, by promoting its mechanical reduction in the act of mastication, and by facilitating the subsequent admixture of other watery fluids, and besides the material assistance which it affords to the act of deglutition, the Saliva fulfils other and perhaps still more important purposes. Without its solvent action on many of the solid constituents of our food, their taste would be either greatly diminished in intensity or altogether lost. Moreover, by lubricating the surfaces of the mouth and teeth it prevents the adhesion of viscous substances, whilst its presence is of great importance in enabling the tongue to perform the rapid movements requisite for distinct articulation, as is clearly indicated by the thick and almost unintelligible utterance of those in whom from any cause the mouth and

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results of the above observations, has been brought to light by Prof. Owen; for he ascertained that in the Great Ant-eater (*Myrmecophaga jubata*), whose enormously elongated tongue is kept moist by a large quantity of a peculiarly viscid saliva, for the purpose of entrapping its prey, the Parotid gland is of no unusual size, whilst the Submaxillary gland extends not only along a great part of the elongated jaws, but backwards into the neck.

* "C. Rend." xxi. p. 362.

† "Human Physiology," 1861, p. 112.

tongue have become dry and parched. Lastly there can be no doubt that it has itself a powerful chemical action upon the farinaceous constituents of food; for it has been shown by Mialhe that one part of Ptyalin dissolved in water can effect the conversion of 2000 parts of Starch, first into dextrine and then into grape sugar. The rapidity with which this takes place under favourable circumstances is very great; thus Vintschgau[*] found that if well boiled, thin starch paste, which had been rendered blue by the addition of Iodine were added drop by drop to Saliva at a temperature of 98° or 99° F. the colour instantly disappeared; and Dr. Dalton found traces of Sugar in Starch-paste which had been kept in the mouth within 30 seconds. This power is not peculiar, however, to the Saliva; for M. Bernard has shown that many azotized substances, in a state of incipient decomposition, exert a similar agency: still it appears to be possessed by ptyalin in a much greater degree than by any of these (save the pancreatic fluid, which resembles saliva in this property), the transformation of starch under its influence commencing immediately, and continuing energetically until it is entirely effected. Human Saliva appears to be more powerful than that of animals; since not only is the secretion of any one of the glands sufficient to effect this conversion, (though undoubtedly the energy of the action is materially increased by the admixture of the Saliva flowing from all the glands), but the transforming process is certainly not checked on the passage of the food into the stomach, which is probably partly the result of the larger proportion of Ptyalin which the Saliva of Man contains as compared with that of the Horse or Dog, and partly to the acidity of Human Gastric Juice being much less than that secreted by the latter of these animals.[†] In reference to the other constituents of our food, Longet[‡] and Harley believe that the mixed Saliva possesses a slight emulsifying power on oleaginous substances; but no satisfactory evidence has yet been obtained that the Saliva has any chemical action upon azotized compounds; consequently, as regards these constituents of the food, its operation must be considered as purely physical, and we shall find that a different secretion is provided for *their* transformation, which has no action upon farinaceous matter. The secretion of the Saliva takes place intermittingly under nervous influence, the conditions of which have been very carefully investigated by Bernard,[§] Eckhard,[||] Schiff,[¶] Adrian, and others, in the dog. The submaxillary and sublingual glands are supplied by the chorda tympani and by branches of the sympathetic, the different action of which upon the glands, when stimulated, is very curious, effecting actually a change in the character of the Saliva secreted. If the parts are cleanly dissected out, the glands may be seen at rest, secreting little or no saliva, whilst the venous blood returning from them is of a dark tint. If a drop of vinegar be now placed upon the tongue of the animal, the arterial twigs supplying the gland immediately enlarge, the rapidity of the current of blood is increased, the veins pulsate and convey scarlet blood, and an abundant discharge of limpid saliva takes place. These conditions are brought about by a reflex action transmitted through the sensory branches of the gustatory and glossopharyngeal nerves, and through motor nerves contained in the chorda tympani and primarily derived from the facial; for if either of these latter nerves be cut, the current of blood becomes slower, its colour in the veins black, the secretion of Saliva diminishes, and vinegar placed on the tongue no longer excites the secretion; whilst, if their cut extremities be again irritated, all the former phenomena recur. That the secretion does not wholly cease after section of the chorda tympani, is believed by Bernard* to be due to the reflex action of the submaxillary ganglion, as it is entirely stopped when that ganglion is also removed. On the other hand, if the sympathetic branches proceeding to these glands be irritated, the current of blood becomes very slow, in consequence of the contraction of the vessels, its colour in the veins very dark, and the secretion of Saliva, whilst it diminishes in quantity, becomes at the same time remarkably viscous, and contains, according to Eckhard, a remarkable number of the sarcode-like bodies possessing the power of spontaneous movement.—In reference to the Parotid glands, Bernard supposed that the branch through which the nervous energy was conveyed, ordinarily stimulating them to activity, was derived from an anastomosing loop between the facial and the auricular branch of the Fifth, irritation of this nerve causing a profuse secretion of watery Saliva. Eckhard, however, considers that the facial nerve has no influence upon the flow of parotidean Saliva, and that the motor nerves of this gland are exclusively derived from the auriculo-temporal nerve. Irritation of the Sympathetic does not appear to alter in any way the characters of the secretion, as in the case of the submaxillary gland, but simply effects a diminution in its quantity. It may be observed, in conclusion, that the Saliva can be excited to flow—1. By direct irritation of the cut extremities of the Chorda Tympani nerve of the Facial, of the Fifth, (though the petrosal nerve may also have been excited, Schiff), and of the Sympathetic cord in the neck (Ludwig). 2. By the reflex action (*a*) of the submaxillary ganglion, and (*b*) of the brain and spinal cord, excited through impressions conveyed by the Glossopharyngeal and gustatory of the Fifth, and taking effect through the motor branches of the Facial running in the chorda tympani. 3. By mental stimuli, as by the sight or thought of sapid food. 4. By poisons circulating in the blood, as camphor, woorara, and the salts of mercury. 5. By the lesion of certain parts of the encephalon, as the floor of the fourth ventricle (Bernard).

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[*] "Atti del Instituto Veneto," t. iv. 1859.

[†] See v. Gorup-Besanez, "Physiolog. Chemie," p. 437; Eckhard, Ordenstein, and Biervliet in "Canstatt's Jahresbericht," for 1859, p. 117; 1862, p. 110.

[‡] "Physiologie," 1861, p. 175.

[§] Lectures, "Med. Times and Gaz.," vol. i. 1860, p. 288-361.

[||] "Beiträge," band ii, p. 205; iii, 1862, p. 41.

[¶] "Physiologie," 1859, p. 393.

81. On its entrance into the Stomach, the food is subjected to the operation of the *Gastric Juice*, which is secreted by the follicles in its walls, or by a certain part of them. This follicular apparatus is extremely extensive, and makes up the chief part of the thickness of the gastric mucous membrane. If this be divided by a section perpendicular to the surface (Fig. 10), it is seen to be almost entirely composed of a multitude of parallel tubuli closely applied to each other, their cæcal extremities abutting against the submucous tissue, and their open ends being directed towards the cavity of the Stomach. Between the tubuli, blood-vessels pass-up from the submucous tissue, and from a vascular network on its surface, in the interspaces of which the orifices of the

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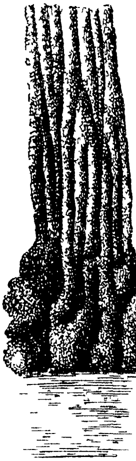
* "Bibliothèque Universelle," 1863, p. 262. Ablation of the submaxillary ganglion occasions a continuous instead of an intermittent secretion of Saliva from the submaxillary gland.

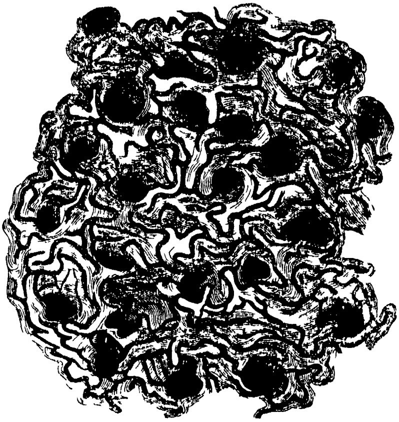
tubes are seen (Fig. 11). These tubular glands, whose number is estimated by Sappey at nearly five millions,* however, have not everywhere the same structure. In that which may be considered as their most characteristic form, and which presents itself over the greater part of the area of the membrane, the wide open orifice leads to a pit of no great depth (Fig. 12, *a*), lined by cylinder-epithelium resembling that of the surface with which it is continuous; and from the bottom of this pit, two or more passages (*b*, *b*) branch-off, still lined by cylinder-epithelium, which speedily subdivide into the proper glandular cæca (*c*, *c*). Each of these cæca, when sufficiently magnified (Fig. 13), is found to be composed of a delicate basement-membrane (*a*), inflected over a series of nearly globular cells (*b*), which occupy almost the whole cavity of the tube, and which contain a finely-granular matter; the narrow passage left vacant in the centre, however, is still surrounded by a layer of epithelial cells (*c*), whose small size is in striking contrast to the large dimensions of the gland-cells. When a transverse section is made through a cluster of cæca connected with a single external orifice, they are found to be held-together in a bundle (Fig. 14) by the interposition of areolar tissue, a thicker layer of which surrounds the whole fasciculus, and isolates it from others; whilst between the cæca are observed the orifices (*a*, *a*) of the divided capillary vessels which pass-up amongst them.—A different type of glandular structure frequently presents itself, however, especially near the pylorus; for the superficial orifice leads into a long and wide follicle (Fig. 15, *a*), lined with cylinder-epithelium, and branching-out, as it approaches the submucous tissue, into a small num-

FIG. 10.



Vertical section of the *Mucous Membrane of the Stomach*, near the pylorus; magnified 20 times.

FIG 11.



Capillary network of the lining membrane of the *Stomach*, with the orifices of the *gastric follicles*.

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* Henle, "Anatomie," 1862, p. 159.

ber of short follicles (*b b*), still lined by an epithelium of the same kind.

FIG. 12.

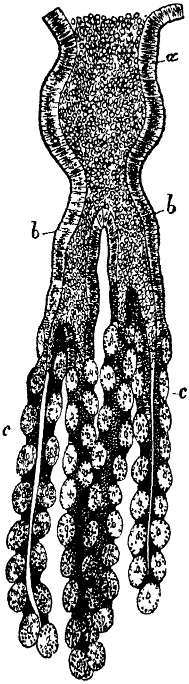


FIG. 13.

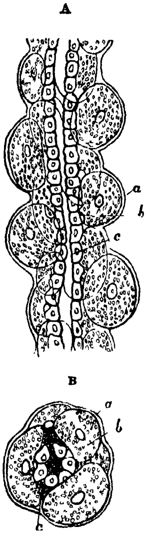
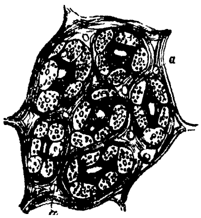


FIG. 12. *Peptic gastric gland*;—*a*, common trunk; *b, b*, its chief branches; *c, c*, terminal cæca with spheroidal gland-cells.

FIG. 13. Portions of one of the cæca more highly magnified, as seen longitudinally (A), and in transverse section (B);—*a*, basement membrane; *b*, large glandular cell; *c*, small epithelium-cells surrounding the cavity.

Kölliker* and Goll have clearly shown that we must consider the first of them as the instrument of the secretion of gastric fluid, while the office of the second is simply to furnish mucus for the protection of the membrane. For in the Dog and Pig, in which the limitation of the two kinds of glands to particular regions of the stomach (the former to the great curvature and the middle portion, the latter to the pyloric portion) is well marked, it has been found that only the follicles with globular cells furnish a substance possessing a solvent power for protein-compounds, the secretion of the follicles lined by cylinder-epithelium being destitute of this property, and agreeing with ordinary mucus.† According to M. Cl. Bernard, when the stomach is empty, the cylindrical epithelium which lines them completely blocks-up their orifices, so that during fasting these appear as slightly-prominent papillæ; but when the secretion of gastric fluid commences,

FIG. 14.



Transverse section passing through a cluster of gastric cæca, separated and surrounded by fibrous tissues; *a, a*, orifices of divided capillaries.

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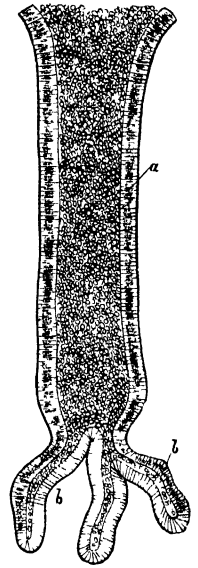
* "Mikroskop. Anat." 1860, p. 321.

† The best accounts of the structure of the mucous membrane of the stomach, and of the gastric glands, are given by Messrs. Todd and Bowman, "Physiological Anatomy,"

this epithelium is cast-forth by the pressure from beneath.* The so-called lenticular or solitary glands are found scattered here and there in the substance of the mucous membrane, and present a close analogy to those found in the small intestine. The interior surface of the stomach, thrown by contraction when the viscus is empty into irregular folds or rugæ (Fig. 16 A), presents throughout the greater part of its extent, and especially near the Pylorus, small vascular processes or prolongations of the mucous membrane (B),† resembling the villi of the small intestine, of which they must be considered as the rudimentary condition, but differing essentially from them in the circumstance that they contain no lacteal vessels. The lymphatics of the stomach are stated by Teichmann‡ to form two layers, a superficial and close network surrounding the cæcal extremities of the peptic glands, and a deeper layer with larger meshes lying in the submucous areolar tissue, and separated from the first by the thin stratum of involuntary muscular fibre, described by Brücke as the muscular layer of the mucous membrane, through which many vessels connecting the two strata pass.

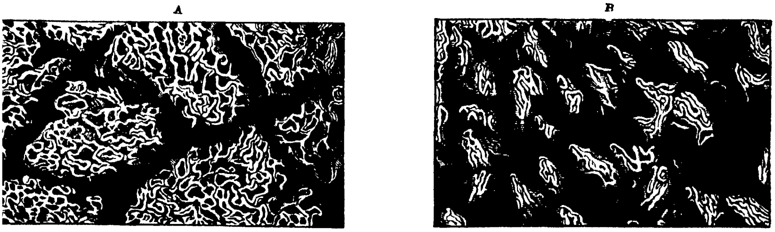
Fig. 15.



Mucous gastric gland, with cylinder-epithelium; *a*, wide trunk; *b*, *b*, its cæcal appendages.

82. The nature and composition of the *Gastric Juice* which is secreted and poured-forth by the peptic follicles, have been the subjects of much discussion among Chemists; and though certain points may be considered as satisfactorily determined, there are others which still remain doubtful.—This liquid, when obtained without admixture with saliva, is clear, transparent,

Fig. 16.



Appearance of the lining membrane of the *Stomach*, in an injected preparation:—A, from the convex surface of the rugæ;—B, from the neighbourhood of the pylorus, where the orifices of the gastric follicles occupy the interspaces of the deepest portions of the vascular network.

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vol. ii. pp. 190 *et seq.*; by Prof. Kolliker, "Mikroskopische Anatomie," band ii. § 163; by Dr. Brinton, in the Supp. to the "Cyc. Anatomy and Physiology," and by the same writer in the "Med.-Chir. Rev.," July 1862, p. 189.

* "Gazette Médicale," Mars, 1844.

† This fact was first brought into prominent notice by Dr. Neill, in his Memoir 'On the Structure of the Mucous Membrane of the Human Stomach,' in the "Amer. Journ. of Med. Sci.," Jan. 1851.

‡ "Das Sangader System," 1861, p. 76.

colourless or slightly yellow, and has very little viscidity. Microscopic examination indicates the persistence of a few of the cells exuviated from the interior of the gastric follicles; but these for the most part leave no other traces than their nuclei and a fine molecular matter arising from their disintegration. The proportion of solid matter which the Gastric Juice contains, and the proportion which its chief organic constituent—the *pepsin*, or 'gastric ferment'—bears to the inorganic residue, seem to vary greatly in different animals. The following table shows the composition of the Gastric Juice as obtained from the best analyses in man and some animals:—*

	Man, mixed with Saliva. C. Schmidt.	*Dog.* C. Schmidt.		*Sheep.* Schmidt.	*Horse.* Frerichs.
		Without saliva.	With saliva.		
Water	994·40	973 0	971·2	986·15	982·8
Solid residue	5·60	27·0	28·8	13·85	17·2
Organic matters (Ferment: Pepsin)	3·19	17·1	17·3	4·05	9·8
Inorganic matters—					
Chloride of sodium	1·46	2·5	3·1	4·36	7·4
Chloride of potassium	0·55	1·1	1·1	1·52	
Chloride of calcium	0·06	0·6	1·7	0·11	
Chloride of ammonium	—	0·5	0·5	0·47	
Free Hydrochloric acid	0·20	3·1	2·3	1·23	
Phosphate of lime	0·12	1·7	2·3	1·18	
Phosphate of magnesia		0·2	0·3	0·57	
Phosphate of iron		0·1	0·1	0·33	

83. The most characteristic feature of the Gastric Juice is its decided *acidity*, which is very perceptible to the taste, and is constant throughout the animal kingdom. With regard to the nature of the acid, however, there has been much discrepancy of opinion amongst Chemists; for, simple as the problem of its determination might seem, yet it is complicated by the very peculiar property which lactic acid possesses, of decomposing the alkaline chlorides at a certain elevation of temperature, the degree being partly determined by the strength of the solution. Hence, supposing lactic acid to be present in the stomach with chloride of sodium, the fluid which passes over by distillation will at first be destitute of hydrochloric acid; but, as the liquor becomes more concentrated, and the temperature rises, hydrochloric acid will appear. This, it has been alleged by Bernard and other Chemists, is the true source of the Hydrochloric acid which may be always obtained from the gastric juice by this method; and it is affirmed by them that Lactic acid is the real agent in the solvent process to which that fluid is subservient, the presence of free lactic acid in the stomach having been determined by other means. In like manner, Dr. F. G. Smith,† on examining the contents of the stomach of Alexis St. Martin, two-and-a-half hours after a small quantity of bread had been eaten, obtained evidence of the presence of lactic, and of the absence of all but the slightest trace of hydrochloric acid. On the other hand, the great readiness with which hydrochloric acid was

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* v. Gorup-Besanez, "Phys. Chem.," 1862, p. 460.

† "Experim. upon Digestion," Philadelphia, 1856.

obtained many years ago by Prof. Dunglison from the pure gastric fluid drawn from the stomach of Alexis St. Martin, and the fact that the smell of hydrochloric acid might be distinctly recognised in the fresh juice,[*] are strong evidences in favour of the belief that (as originally maintained by Dr. Prout) free hydrochloric acid is present in this fluid, and that it is the principal if not the only source of its acidity. And an opportunity having been afforded to Dr. Bence Jones, of obtaining a fluid continually vomited in large quantities from the stomach of a patient affected with Sarcina ventriculi, and this fluid, which presented all the ostensible characters of Gastric juice, having been placed in the hands of Prof. Graham for examination, this distinguished Chemist has succeeded in separating hydrochloric acid from it by his method of 'liquid diffusion,' which is not open to the objection that applies to distillation; and although he has found free lactic acid to be also present, its quantity is comparatively small.[†] It appears, then, to be a reasonable conclusion, that whilst hydrochloric acid is originally poured forth, and is therefore the acid obtained by those experimenters, who have employed mechanical irritation to the empty stomach; other acids, as the lactic, butyric, or even acetic, may be formed during digestion, and may thus have been obtained by those who have examined the contents of the stomach only during or towards the close of that process. Allowance must also be made for differences existing in different animals, and perhaps also at different ages, since M. Wasmann has remarked that the pepsin of the stomach of the pig is entirely destitute of the power to coagulate milk, although the pepsin of the stomach of the calf possesses it in a very high degree; from which he is led to suppose that the power of the latter depends upon a particular modification of pepsin, or perhaps upon another substance accompanying it, which ceases to be formed when the young animal is no longer nourished by the milk of its mother.[‡]

84. The peculiar organic 'ferment' of the Gastric juice, to which the name of *Pepsin* has been given, was first obtained in an isolated state by Wasmann; who has given the following account of the properties and reactions of that which he procured from the mucous membrane of the stomach of the Pig, which greatly resembles that of Man. When this membrane is digested in a large quantity of water at from 85° to 95°, many other matters are removed from it besides pepsin; but if this water be poured-off, and the digestion be continued with fresh water in the cold, very little but pepsin is then taken-up. Pepsin appears to be but sparingly soluble in water; when its solution is evaporated to dryness, there remains a greyish, viscid mass, with the odour of glue, and having the appearance of an extract. The solution of this in water is turbid, and still possesses a portion of the characteristic power of pepsin, but greatly reduced. When strong alcohol is added to a fresh solution of pepsin, the latter is precipitated in white flocks, which may be collected on a filter, and produce

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[*] See Prof. Dunglison's "Human Physiology," 7th edit., vol i. pp. 535–6.

[†] For his knowledge of this fact, the Author is indebted to Prof. Graham.—That Hydrochloric acid is the source of the acidity of the gastric juice has also been maintained by Enderlin ("Canstatt's Jahresbericht," 1843, p. 149), and recently by Hubbenet ("Disquisitiones de Succo Gastrico," diss. inaug., Dorpat, 1850), by Bidder and Schmidt ("Die Verdauungssaefte und der Stoffwechsel"), and by Gruenewaldt and Schroeder in their Theses just cited.

[‡] See Prof. Graham's "Elements of Chemistry," pp. 1031-1033.

a grey compact mass when dried. Pepsin enters into chemical combination with many acids, forming compounds which still redden litmus paper; and it is when thus united with acetic and muriatic acids, that its solvent powers are the greatest. The recent investigations of Brücke* appear to prove that pepsin is secreted and stored-up in the cells of the stomach in the neutral state, and that it is only at the moment of discharge that it becomes mingled with the acid; the origin of which last, however, he does not attempt to explain. He found in the course of his experiments, that if the stomach of an animal be thoroughly washed with water till all trace of acidity is removed, a fresh portion of pepsin can be obtained on further maceration, possessing a perfectly neutral reaction. In his last researches he obtained pure pepsin by digesting the finely-divided stomach with diluted phosphoric acid, and precipitating with lime water, when the pepsin fell strongly adherent to the phosphate of lime; it was then dissolved in diluted hydrochloric acid, and the solution treated with a solution of cholesterine; the pepsin again fell, adhering to the cholesterine, from which it was separated by ether. The pepsin so obtained was certainly not an albuminous substance, since it gave no precipitate with nitric acid, corrosive sublimate, tannic acid, or iodine; though when mingled with a dilute solution of hydrochloric acid, it exerted active solvent powers on albumen. These observations, which naturally suggest that the acid gastric juice is not secreted as a whole by any one set of glands, but that the pepsin and hydrochloric or lactic acid are formed separately, is singularly corroborated by an experiment which led Bernard† to the same conclusion, for he injected successively lactate of iron and ferrocyanide of potassium into the jugular vein of a rabbit, and found that on account of the alkalinity of the blood and secretions, and of the tissues generally, no blue discolouration was anywhere perceptible in them, though on the addition of a drop of sulphuric or other acid to any part of the body, Prussian blue discolouration was immediately produced. Now, on examining the stomach, the gastric follicles were colourless, but the surface of the mucous membrane was uniformly discoloured; whence it appears that the acid of the gastric juice is formed, or at least excreted, by the most superficial cellular layers of the gastric mucous membrane.—The solvent power of the gastric juice is difficult to determine, since it differs with the animal and with the nature of the food. The gastric juice of Carnivora is the most active, then that of Herbivora, whilst that of Man appears to be comparatively feeble; and in this point, therefore, he appears to be most closely allied to the Herbivora. Lehmann and Corvisart estimated that on the average 20 oz. of the gastric juice of the dog were required to dissolve 1 oz. of coagulated albumen; but M. Koopmans‡ showed that whilst the strongly acid gastric juice of the Carnivora was best adapted for the solution of animal albumen, the weakly acid gastric juice of the Herbivora was far more efficacious in dissolving vegetable albumen or gluten. In complete corroboration of these results are those of M. Brücke,§ who observed the quantity of fibrin which was dissolved in half-an-hour by a olution of pepsin with one-part of hydrochloric acid. He then added to uccessive portions of the pepsin solution 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, nd 12 parts of hydrochloric acid, and found that to dissolve the same uantity of fibrin, 1, 3, 4, 5, 7, 14, 18, 24, 41, and 102 hours were espectively required. If still more acid were added, the solution was ot completed till after the expiration of eight days or more. Hence it ppears that weakly acid gastric juice is the best solvent for fibrin. In ther experiments Brucke observed that whilst an artificial gastric juice ontaining 0·1 per cent of acid was the most advantageous for the digesion of fibrin, an acid of double that strength, or 0·2 per cent, was est adapted to effect the rapid solution of coagulated albumen. From hese experiments we may draw the conclusion that, in enfeebled condiions of the stomach, preparations of gluten should be administered instead f the albuminous compounds of animal origin; and they may serve to xplain the advantage resulting from the employment of uncooked meat the wasting diseases of children.

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* "Beiträge zur Lehre von der Verdauung Sitz.-Bericht der K. Akad d. Wiss. Wien," 1859, p. 131 *et seq.* and band xliii. 1861, p. 601.

† "Leçons," 1859, p. 376–377.

‡ "Nederland Lancet," t. v. 1856.

§ "Sitzungsbericht der Wien Akad.," 1859, p. 131; 1861, p. 601.

85. It is only when either alimentary or some other substances capable f exciting irritation, are present in the stomach, that the gastric juice poured forth. So long as it is empty, the secretion which moistens s walls is neutral or even alkaline; but as soon as food is taken, acid poured forth, and this in increasing quantities, until a certain time fter the commencement of the digestive process, when the acidity of the omach is at its maximum. In proportion as the alimentary matter is issolved, however, and is either at once absorbed, or escapes through e pyloric orifice, the acidity of the stomach diminishes; and as soon its cavity is emptied, the secretion of its walls is neutral again.[*]—It is ifficult to give even an approximative estimate of the quantity of fluid us poured forth from the walls of the stomach. Any attempts to determine it by calculating what would be required to dissolve the whole of e albuminous compounds ingested, are very unsatisfactory; since the ower of dissolving these is possessed by other fluids, rendering the cretion of a much smaller amount of gastric juice requisite than would herwise be the case. Corvisart, from experiments on dogs,[†] estimates it at out 1-20th of the weight of the animal per diem; Harley,[‡] at 1-15th; ehmann, at 1-10th; whilst Grunewaldt obtained nearly ¾ lb. avoird. om a woman of 116 lbs. weight, with a gastric fistula, in 15 minutes;[§] d Schmidt gives as the mean of experiments on the same woman, 580 ains hourly, or 30·8 lbs. av. of gastric juice per diem.[||]

86. A very important series of observations on the conditions under hich the gastric juice is secreted, was made some years since by Dr. eaumont, in the remarkable case of Alexis St. Martin, already several mes referred to.[¶] "The inner coat of the stomach (as seen through e fistulous orifice) in its natural and healthy state, is of a light or pale nk colour, varying in its hues, according to its full or empty state.

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[*] See Dr. Bence Jones, in "Medical Times," June 14, 1852.

[†] Longet, "Physiologie," 1861, p. 183, vol. i.

[‡] "Med.-Chir. Review," 1860, p. 211.

[§] Quoted by M. Edwards, "Leçons," t. vii., 1862, p. 24.

[||] "Annal. der Chemie von Liebig und Wohler," vol. xcii. p. 42.

[¶] See Dr. Beaumont's "Experiments and Observations on the Gastric Juice and the ysiology of Digestion," reprinted with notes by Dr. Andrew Combe, Edinb., 1838.

It is of a soft or velvet-like appearance, and is constantly covered with a very thin, transparent viscid mucus, lining the whole interior of the organ. By applying aliment or other irritants to the internal coat of the stomach, and observing the effect through a magnifying glass, innumerable lucid points, and very fine [nervous or vascular] papillæ can be seen arising from the villous membrane, and protruding through the mucous coat, from which distils a pure, limpid, colourless, slightly viscid fluid." (The papillæ here described appear to be the orifices of the gastric follicles, which are usually closed by their epithelial cells during fasting, and which would seem to become prominent when the *vis a tergo* of the secreted fluid first causes this plug of cells to be cast forth.) "The fluid thus excited is invariably distinctly acid. The mucus of the stomach is less fluid, more viscid or albuminous, semi-opaque, sometimes a little saltish, and does not possess the slightest character of acidity. The gastric fluid never appears to be accumulated in the cavity of the stomach while fasting; and is seldom, if ever, discharged from its proper secerning vessels, except when excited by the natural stimulus of aliment, mechanical irritation of tubes, or other excitants. When aliment is received, the juice is given out in exact proportion to its requirements for solution, except when more food has been taken than is necessary for the wants of the system."—The observations of Dr. Beaumont have been confirmed by those of M. Blondlot* and of M. Cl. Bernard,† which were made upon Dogs in whose stomachs fistulous openings were maintained for a length of time. They found that the flow of gastric fluid is more excited by pepper, salt, and soluble stimulants, than it is by mechanical irritation; and that if mechanical irritation be carried beyond certain limits, so as to produce pain, the secretion, instead of being more abundant, diminishes or ceases entirely; whilst a ropy mucus is poured out instead, and the movements of the stomach are considerably increased. The animal at the same time appears ill at ease, is agitated, has nausea, and, if the irritation be continued, actual vomiting; and bile has been observed to flow into the stomach, and escape by the fistulous opening. Similar disorders of the functions of the stomach result from violent pain in other parts of the body; the process of digestion in such cases being suspended, and sometimes vomiting excited. When acidulated substances, as food rendered acid by the addition of a little vinegar, were introduced into the stomach, the quantity of gastric fluid poured-out was much smaller, and the digestive process consequently slower, than when similar food, rendered alkaline by a weak solution of carbonate of soda, was introduced. If, however, instead of a weak solution, carbonate of soda in crystal or in powder was introduced into the stomach, a large quantity of mucus and bile, instead of gastric fluid, flowed into the stomach; and vomiting and purging very often followed. When very cold water, or small pieces of ice, were introduced into the stomach, the mucous membrane was at first rendered very pallid; but soon a kind of reaction followed, the membrane became turgid with blood, and a large quantity of gastric fluid was secreted. If, however, too much ice was employed, the animal appeared ill, and shivered; and digestion, instead of being rendered more active, was retarded. Moderate heat, applied to the mucous surface of the stomach, appeared to have no particular action on digestion; but a high degree of heat produced most serious consequences. Thus the introduction of a little boiling water threw the animal at once into a kind of adynamic state, which was followed by death in three or four hours; the mucous membrane of the stomach was found red and swollen, whilst an abundant exudation of blackish blood had taken place into the cavity of the organ. Similar injurious effects resulted, in a greater or less degree, from the introduction of other irritants, such as nitrate of silver or ammonia; the digestive functions being at once abolished, and the mucous surface of the organ rendered highly sensitive.

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* "Traité Analytique de la Digestion."

† "Archiv. d'Anat. Gén. et de Physiol.," Jan. 1846.

87. That the quantity of the Gastric Juice secreted from the walls of the stomach depends rather upon the general requirements of the system, than upon the quantity of food introduced into the digestive cavity, is a principle of the highest practical importance, and cannot be too steadily kept in view in Dietetics. A *definite proportion* only of aliment can be perfectly digested in a given quantity of the fluid; the action of which, like other chemical operations, ceases after having been exercised on a fixed and definite amount of matter. "When the juice has become saturated, it refuses to dissolve more; and, if an excess of food has been taken, the residue remains in the stomach, or passes into the bowels in a crude state, and becomes a source of nervous irritation, pain, and disease, for a long time." The unfavourable effect of an undue burthen of food upon the Stomach itself, interferes with its healthy action; and thus the quantity really appropriate is not dissolved. The febrile disturbance is thus increased; and the mucous membrane of the stomach exhibits evident indications of its morbid condition. The description of these indications given by Dr. Beaumont, is peculiarly graphic, as well as hygienically important. "In disease, or partial derangement of the healthy function, the mucous membrane presents various and essentially different appearances. In febrile conditions of the system, occasioned by whatever cause,—obstructed perspiration, undue excitement by stimulating liquors, overloading the stomach with food, fear, anger, or whatever depresses or disturbs the nervous system,—the villous coat becomes sometimes red and dry, at other times pale and moist, and loses its smooth and healthy appearance; the secretions become vitiated, greatly diminished, or even suppressed; the coat of mucus scarcely perceptible, the follicles flat and flaccid, with secretions insufficient to prevent the papillæ from irritation. There are sometimes found, on the internal coat of the stomach, eruptions of deep-red pimples, not numerous, but distributed here and there upon the villous membrane, rising above the surface of the mucous coat. These are at first sharp-pointed, and red, but frequently become filled with white purulent matter. At other times, irregular, circumscribed red patches, varying in size and extent from half an inch to an inch and a half in circumference, are found on the internal coat. These appear to be the effects of congestion in the minute blood-vessels of the stomach. There are also seen at times small aphthous crusts, in connection with these red patches. Abrasion of the lining membrane, like the rolling-up of the mucous coat into small shreds or strings, leaving the papillæ bare for an indefinite space, is not an uncommon appearance. These diseased appearances, when very slight, do not always affect essen-

tially the gastric apparatus. When considerable, and particularly when there are corresponding symptoms of disease,—as dryness of the mouth, thirst, accelerated pulse, &c.—*no gastric juice can be extracted by the alimentary stimulus.* Drinks are immediately absorbed or otherwise disposed-of; but food taken in this condition of the stomach remains undigested for twenty-four or forty-eight hours, or more, increasing the derangement of the alimentary canal, and aggravating the general symptoms of disease. After excessive eating or drinking, chymification is retarded; and, though the appetite be not always impaired at first, the fluids become acrid and sharp, excoriating the edges of the aperture, and almost invariably producing aphthous patches and the other indications of a diseased state of the internal membrane. Vitiated bile is also found in the stomach under these circumstances, and flocculi of mucus are more abundant than in health. Whenever this morbid condition of the stomach occurs, with the usual accompanying symptoms of disease, there is generally a corresponding appearance of the tongue. When a healthy state of the stomach is restored, the tongue invariably becomes clean."* The Temperature of the Stomach rises with the increase of vascular and secretory activity which takes place during digestion. Dr. F. Smith found the ordinary temperature of St. Martin's stomach while fasting to be 98°-99° Fahr., whilst during digestion it rose to 100°-101° Fahr.†

88. That the secretion of Gastric Juice is affected in a very marked manner by conditions of the Nervous system, is indicated by the effect of mental emotions in putting an immediate stop to the digestive process, when it is going-on with full vigour. It does not appear to be exactly determined by what channel such influence is conveyed. Experiments which have been made upon animals with a view of ascertaining the share which the nervous influence conveyed by the Pneumogastrics takes in digestion, have, from inattention to important points, led to strangely contradictory results in the hands of different experimenters. Bernard, with many others, considers that division of these nerves instantaneously checks the elaboration of the gastric fluid, and therefore puts a stop to digestion; and he points to the pallor and flaccidity of the stomach which immediately succeed the operation, the slight and superficial digestion of the alimentary mass which takes place, and to the additional circum-

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* Dr. A. Combe's commentary on the above passage is too apposite to be omitted. "Many persons who obviously live too freely, protest against the fact, because they feel no immediate inconvenience, either from the quantity of food, or the stimulants in which they habitually indulge; or, in other words, because they experience no pain, sickness, or headache,—nothing, perhaps, except slight fulness and oppression, which soon go off. Observation extended over a sufficient length of time, however, shows that the conclusion drawn is entirely fallacious, and that the real amount of injury is not felt at the moment, merely because, for a wise purpose, nature has deprived us of any consciousness of either the existence or the state of the stomach during health. In accordance with this, Dr. Beaumont's experiments prove, that extensive erythematic inflammation of the mucous coat of the stomach was of frequent occurrence in St. Martin after excesses in eating, and especially in drinking, even when no marked general symptom was present to indicate its existence. Occasionally, febrile heat, nausea, headache, and thirst were complained of, but not always. Had St. Martin's stomach, and its inflamed patches, not been visible to the eye, he too might have pleaded that his temporary excesses did him no harm; but, when they presented themselves in such legible characters that Dr. Beaumont could not miss seeing them, argument and supposition were at an end, and the broad fact could not be denied."

† Loc. cit.

stance, that in the rabbit there is a sudden change in the reaction of the urine from alkaline to acid, the latter being the normal condition in the fasting state, and therefore showing that all action on the food must have stopped.[*] He further observes, that on galvanizing the pneumogastrics an abundant flow of gastric juice takes place.[†] Longet, however,[‡] maintains, that division of the pneumogastrics operates rather in paralyzing the muscular movements of the stomach than in stopping the secretion of the gastric juice; for he states that if a small quantity of milk were given to the animal 24 or even 48 hours after the section, and when, therefore, there could be no gastric juice remaining in the stomach, it was invariably clotted after death, or upon making the animal vomit; and *small quantities* of meat or other food were digested readily enough, though large masses were only superficially digested, because, the muscular power of the stomach being paralyzed, the food was not properly intermingled with the gastric juice. Dr. John Reid [§] showed long ago that, in some instances at least, a re-establishment of the digestive power manifested itself after an interval of some days, if the animals survived the effect of the operation. In the animals which died within the first four or five days, no indication of this restoration could be discovered by Dr. R.; in those which survived longer, great emaciation took place; but when life was sufficiently prolonged, the power of assimilation seemed almost completely restored. This was the case in four out of the seventeen dogs experimented-on; and the evidence of this restoration consisted in the recovery of flesh and blood by the animals, the vomiting of half-digested food permanently reddening litmus paper, the disappearance of a considerable quantity of alimentary matter from the intestinal canal, and the existence of chyle in the lacteals. So also more recently Budge[||] states, that after careful division of the vagi at the œsophageal opening in rabbits, he observed that the animals ate as freely, secreted as good gastric juice, and digested as naturally as healthy ones; and by careful tending he was enabled to keep them alive for months. He attributes the serious effects which occur in many instances after section of the pneumogastrics in the neck, to the injury inflicted on the pulmonary branches, and to the consequent disturbance of the respiration, which necessarily affects all the other functions.—The observations and experiments of Sedillot and Schiff[¶] fully corroborate Longet's conclusion, that the pneumogastrics are chiefly the motor nerves of the stomach. It may serve to account in some degree for the contrary results obtained by other experimenters, to state that seven out of Dr. R.'s seventeen experiments were performed, before he obtained any evidence of digestion after the operation, and that the four which furnished this followed one another almost in succession; so that it is easy to understand why those who were satisfied with a small number of experiments, should have been led to deny it altogether. The inquiries which have been made in reference to the action of the sympathetic upon the secretion of the gastric juice, are, owing to the difficulties which attend experiments upon this point, comparatively few. Donders* is inclined to think that the secretion is in some measure under the control of the sympathetic, which is so largely distributed to the stomach, and especially to its vessels, and refers to the experiments of Pincus, who endeavoured to show that section of the pneumogastrics had little influence, unless made at the œsophageal foramen, when the sympathetic branches were also divided; the stoppage of the secretion was then observed to be complete and perfect. But we have already seen that this is not the result of the experiments of Budge, and, indeed, the latter observer has extirpated the cœliac and meseraic ganglia, as well as divided the pneumogastrics, and still found (with one exception) that after the lapse of nine hours the stomach gave an acid reaction; and these results are fully corroborated by Ravitsch, who found that section of the vagi at the œsophageal opening, involving section of the sympathetic,† had little or no influence upon either the secretion of the gastric juice or the absorption of the chyme, though the latter may be somewhat prolonged; and by Schiff, who divided the splanchnic nerves without effect. Very recently, also, Adrian ‡ has only obtained negative results as regards the gastric secretion after extirpation of the Cœliac Plexus, which he appears to have accomplished with great dexterity, as the animals lived for months after the operation. Bernard, however, states § that on galvanizing the sympathetic nerves distributed to the stomach, a sudden arrest of the secretion occurred.

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[*] Bernard, "Leçons," 1859, vol. ii. p. 81.

[†] "Med. T. and Gazette," vol. ii. 1860. [‡] "Physiologie," vol. i. p. 236-7, 1861.

[§] "Edinb. Med. and Surg. Journ.," April, 1839; and "Physiological, Anatomical, and Pathological Researches," CHAP. V.—Dr. Reid's results have been confirmed as to this important particular by Hübbenet (Op. cit.) and more recently by Bidder and Schmidt, "Ill. Med. Zeitung," 1852, heft viii. p. 112.

[||] "Physiologie," p. 175, 1862. [¶] "Physiologie," p. 421, 1861.

89. It must be held as demonstrated by these experiments, then, that all the arguments which have been drawn from the effects of lesion of the Pneumogastric and Sympathetic nerves upon the functions of the Stomach, in favour of the doctrine that Secretion *depends upon* Nervous agency must be set aside. That these nerves have an important *influence on* the gastric secretion, is evident from the deficiency in its amount soon after their section, as well as from other facts. But this is a very different proposition from that just alluded-to; and the difference has been very happily illustrated by Dr. Reid. "The movements of a horse," he observes, "are independent of the rider on his back,—in other words, the rider does not furnish the conditions necessary for the movements of the horse;—but every one knows how much these movements may be influenced by the hand and heel of the rider."

90. Our knowledge of the nature of the process of *Gastric Digestion* has been greatly advanced by recent inquiries; and we are now in a condition to state with considerable precision what it is, and what it is not, the province of the gastric juice to effect.—There can no longer be any doubt, that the operation is one essentially of *chemical solution;* and that the *vital* attributes of the Stomach are only exercised in the preparation of the solvent, and in the performance of those movements which promote its action on the alimentary matters submitted to it. The first series of facts which clearly demonstrated this position, were those that

* "Phys.," 1859, vol. i. p. 229.

† "Muller's Archiv," 1861, p. 779.

‡ Eckhard, "Beitrage," band iii. 1862.

§ "Med. T. and Gazette," 1860, vol. ii.

resulted from the very pains-taking observations made by Dr. Beaumont, in the case of St. Martin already referred-to. By introducing a tube of india-rubber into the empty Stomach, Dr. B. was able to obtain a supply of gastric juice whenever he desired it, the tube serving the purpose of stimulating the follicles to pour-forth their secretion, and at the same time conveying it away; and with the fluid thus obtained, he was able to make various experiments, which showed *that the change which it effects upon alimentary matter, when it is kept at a temperature of 98° or 100°, and frequently agitated, is not less complete than that which takes place when the same matter is submitted to its operation within the stomach, but requires a longer time.* This is readily accounted-for when we remember, that no ordinary agitation can produce the same effect with the curious movements of the stomach; and that the continual removal, from its cavity, of the matter which has been already dissolved, must aid the operation of the solvent on the remainder. The following is one out of many experiments detailed by Dr. Beaumont. "At 11½ o'clock, A.M., after having kept the lad fasting for 17 hours, I introduced a gum-elastic tube, and drew off one ounce of pure gastric liquor, unmixed with any other matter, except a small proportion of mucus, into a three-ounce vial. I then took a solid piece of boiled recently-salted beef, weighing three drachms, and put it into the liquor in the vial; corked the vial tight, and placed it in a saucepan filled with water, raised to the temperature of 100°, and kept at that point on a nicely-regulated sand-bath. In *forty* minutes, digestion had distinctly commenced over the surface of the meat. In *fifty* minutes, the fluid had become quite opaque and cloudy; the external texture began to separate and become loose. In *sixty* minutes, chyme began to form. At 1 o'clock, P.M., (digestion having progressed with the same regularity as in the last half-hour), the cellular texture seemed to be entirely destroyed, leaving the muscular fibres loose and unconnected, floating about in fine small shreds, very tender and soft. At 3 o'clock, the muscular fibres had diminished one-half, since the last examination. At 5 o'clock, they were nearly all digested; a few fibres only remaining. At 7 o'clock, the muscular texture was completely broken down, and only a few of the small fibres could be seen floating in the fluid. At 9 o'clock, every part of the meat was completely digested. The gastric juice, when taken from the stomach, was as clear and transparent as water. The mixture in the vial was now about the colour of whey. After standing at rest a few minutes, a fine sediment of the colour of the meat subsided to the bottom of the vial.—A piece of beef, exactly similar to that placed in the vial, was introduced into the stomach, through the aperture, at the same time. At 12 o'clock it was withdrawn, and found to be as little affected by digestion as that in the vial; there was little or no difference in their appearance. It was returned to the stomach; and, on the string being drawn out at 1 o'clock, P.M., the meat was found to be all completely digested and gone. The effect of the gastric juice on the piece of meat suspended in the stomach, was exactly similar to that in the vial, only more rapid after the first half-hour, and sooner completed. Digestion commenced on, and was confined to, the surface entirely in both situations. Agitation accelerated the solution in the vial, by removing the coat that was digested on the surface, enveloping the remainder of the meat in the gastric fluid, and giving this fluid access to the undigested portions."* Many variations were made in other experiments; some of which strikingly displayed the effects of thorough mastication, in aiding both natural and artificial digestion.

91. The attempt was made by Dr. Beaumont, to determine the relative digestibility of different articles of diet, by observing the length of time requisite for their solution.† But, as he himself points-out, the rapidity of digestion varies so greatly, according to the quantity eaten, the nature and amount of the previous exercise, the interval since the preceding meal, the state of health, the condition of the mind, and the nature of the weather, that a much more extended inquiry would be necessary to arrive at results to be depended-on. Some important inferences of a general character, however, may be drawn from his researches. —It seems to be a general rule, that the flesh of wild animals is more easy of digestion than that of the domesticated races which approach them most nearly. This may, perhaps, be partly attributed to the small quantity of fatty matter that is mixed-up with the flesh of the former, whilst that of the latter is largely pervaded by it. For it appears from Dr. B.'s experiments, that the presence in the stomach of any substance which is difficult of digestion, interferes with the solution of food that would otherwise be soon reduced. It seems that, on the whole, Beef is more speedily reduced than Mutton, and Mutton sooner than either Veal or Pork. Fowls are far from possessing the digestibility that is ordinarily imputed to them; but Turkey is, of all kinds of flesh except Venison, the most soluble.—Dr. Beaumont's experiments further show, that *bulk* is as necessary for healthy digestion, as the presence of the nutrient principle itself. This fact has been long known by experience to uncivilized nations. The Kamschatdales, for example, are in the habit of mixing earth or saw-dust with the train-oil on which alone they are frequently reduced to live. The Veddahs or wild hunters of Ceylon, on the same principle, mingle the pounded fibres of soft and decayed wood with the honey on which they feed when meat is not to be had; and on one of them being asked the reason of the practice, he replied, "I cannot tell you, but I know that the belly must be filled." It is further shown by Dr. B., that soups and fluid diet are not more readily chymified than solid aliment, and are not alone fit for the support of the system; and this, also, is conformable to the well-known results of experience; for a dyspeptic patient will frequently reject chicken-broth, when he can retain solid food or a richer soup.—Dr. Beaumont also ascertained, that moderate exercise facilitates digestion, though severe and fatiguing exercise retards it. If even moderate exercise be taken *immediately* after a *full* meal, however, it is probably rather injurious than beneficial; but if an hour be permitted to elapse, or if the quantity of food taken have been small, it is of decided benefit. The influence of temperature on the process of

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* Experiments 2 and 3 of First Series.

† It is important to bear in mind, that the digestibility of different substances bears no relation to their nutrient value, which is entirely dependent on their chemical composition. Of course, however nutritious a substance may be, it is valueless as an article of diet if it cannot be dissolved; but, on the other hand, substances which are very easily digested (such as farinaceous matters) may have a low nutritive value, through containing but a very small proportion of azotized constituents.

solution, is remarkably shown in some of Dr. B.'s experiments. He found that the gastric juice had scarcely any influence on the food submitted to it, when the bottle was exposed to the cold air, instead of being kept at a temperature of 100°. He observed on one occasion, that the injection of a single gill of water at 50° into the stomach, sufficed to lower its temperature upwards of 30°; and that its natural heat was not restored for more than half an hour. Hence the practice of eating ice after dinner, or even of drinking largely of cold fluids, is very prejudicial to digestion.

92. It is far from being true, however, that (according to the older views of its power) the Gastric juice is capable of acting upon *all* the nutritive components of the food. The mistake probably arose from the *reduction* to which these matters are subjected in digestion, the alimentary bolus being completely disintegrated, and its particles saturated with the fluids of the stomach, so that the whole forms a homogeneous liquid of pultaceous consistence, to which the name of *chyme* is given. This chyme will, of course, vary greatly in its composition, according to the proportion of the different alimentary substances that have entered into the composition of the food; and its appearance, also, is far from uniform, being sometimes like gruel, but sometimes more creamy, always, however, having a strong acid reaction.—All the more recent and accurate experiments of those who have studied the chemistry of digestion, lead to the conclusion, that the solvent powers of the Gastric juice are entirely limited to *azotized* substances; and that it exerts no action whatever, upon either starchy, saccharine, or oleaginous matters.* Although the change in the starchy particles, which commences in the mouth, is usually continued in the stomach, yet its continuance is entirely dependent upon the presence of the salivary fluid; being completely checked, when, by tying the œsophagus, that fluid is prevented from passing into the stomach.† Saccharine matters, being readily soluble in water, do not require the agency of the gastric fluid for any other purpose than the solution of their investments, whereby they are set free; and it does not appear that it exerts any converting power upon them. So, again, Oleaginous matters are merely liquefied and reduced to a state of fine division, and are diffused in a state of suspension through the pulpy chyme. According to the researches of Meissner and others‡ the solution contains two new substances, Peptone and Parapeptone, whatever may have been the albuminous compound originally introduced into the stomach. Neither of these two new compounds, into which the Albumen, Syntonin, Fibrin, or Gluten have been divided, are precipitable by heat; from which it is

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* For although in Dr. Smith's experiments on Alex. St. Martin (*loc. cit.*) Glycose was found in the contents of the stomach, when bread and water were introduced through the fistulous orifice and withdrawn after an hour and a half, the man carefully avoiding to swallow his saliva during that period; its formation may with great probability be attributed to the conjoint action of the warmth and moisture of the stomach, and by no means proves any converting agency to have been exercised upon it by the gastric juice.

† See Frerichs in "Wagner's Handwörterbuch," band iii. Art. 'Verdauung.'

‡ See a series of six papers published by Meissner in "Henle and Pfeuffer's Zeitschrift." No. vi., the most recent, is in band xiv. p. 78. No. v., band xiii. (Berichte), p. 265. No. iv. band xii. p. 46. No. iii. band x. p. i. No. ii. band viii., p. 280. No. i. band vii., p. 1. For Brücke's experiments see "Sitzungsbericht d. K. Akad. e Wien," xxxvii.; and for Funke's see "Archiv für Path. Anat.," band xiii. p. 449.

obvious that a process of chemical transformation, as well as of solution, has taken place,—a conclusion which is further corroborated by the experiments of Bernard, who found that on injecting a solution of albumen in very dilute hydrochloric acid into the general circulation, the liquid speedily passed off by the renal secretion, whilst after injecting the solution of albumen in gastric juice no trace of this could be detected in the urine. The two compounds may be separated from one another by the simple neutralization of the acid liquid by an alkali, when a small quantity of a white flocculent precipitate, insoluble in pure water, but slowly dissolved by feebly acid and alkaline fluids, falls, which is termed Parapeptone. By far the larger proportion of the albuminous substance, however, is converted into Peptone, which is contained in the fluid from which the Parapeptone has been precipitated, but is thrown down from its solution as a white colourless substance on the addition of alcohol, corrosive sublimate, or tannic acid. Millon's reagent,* which imparts a red colour to albumen (solid or dissolved) when heated to 140°-202° Fahr. reddens it, but gives no precipitate.† It is remarkable that protracted boiling in water, and also exposure to the action of ozone, produce metamorphoses on albuminous substances analogous to those effected by the act of digestion.—Gelatine and Gelatine-yielding tissues, as the connecting tissue, tendons, ligaments, &c., are reduced, according to Metzler, by the action of the gastric juice to a syrupy fluid,‡ which has no power of coagulation, though it gives the ordinary reactions of Gelatine. Its diffusibility, or power of passing through animal membranes, is somewhat increased.—Meissner, on the other hand, considers it undergoes a change analogous to, though not exactly identical with, those experienced by the albuminous compounds in the stomach; and recently Meissner and Kirchner find that Gelatine is not necessarily deprived of its coagulability by the action of the Gastric Juice.§ The action of the gastric juice, therefore, seems to stand in the place of a high temperature and a powerful oxidizing agent; but though albuminous substances are converted into peptones during digestion, yet as no peptones are found in the fluids of the body, but simply albumen, this conversion seems to be only accomplished for the purpose of promoting its absorption. For, as Prof. Graham has shown, albumen has a very low diffusive power, and a very high endosmotic equivalent; and although, when subjected to considerable pressure, its solutions will filter slowly through animal membranes (thus affording a rationale of its occasional appearance in various transudations), yet it is obvious that unless some such preliminary change took place, a

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[*] A solution of mercury in nitric acid (containing a proto and a persalt).

[†] Other compounds named metapeptones and dyspeptones, obtained by Meissner from casein, syntonin, and other albuminous substances, appear to be only intermediate steps in the main process of their decomposition into a larger portion—peptone, soluble in pure water, and a smaller portion, parapeptone, insoluble in pure water; and Meissner suggests that the operation of the Pancreatic Juice may be to convert parapeptone into peptone, and by thus rendering it soluble, to make it available for the purposes of nutrition. See for v. Wittich's 'Expts. on Peptones,' "Königsb. Med. Jahrb.," band iii. 1862, p. 196 to 207.

[‡] Henle and Meissner, "Bericht," 1860, p. 269.

[§] "Henle and Pfeuf. Zeits.," band xiv. 1862, p. 303.

very insufficient supply of this material would gain entrance into the blood.

93. This action of the Gastric solvent upon the azotized constituents of the food, is dependent upon several accessory conditions. One of the most important of these is *temperature.* A heat of from 96° to 100° is required to keep-up the solvent process, which is retarded according to the depression of the thermometer below this standard; so that at the ordinary temperature of the atmosphere it is completely suspended, to be renewed, however, with an increment of heat. On the other hand, a trifling elevation of temperature above 100° occasions a decomposition in the gastric juice, which entirely destroys its solvent power.—The next condition, which specially affects the time required for the process of solution, is *motion.* This does not act mechanically, by way of 'trituration,' as was once supposed; for food is found to be digested, when enclosed in metallic balls perforated to admit the access of gastric juice to their interior. But it answers the purpose of thoroughly subjecting the whole of the alimentary bolus to the agency of the gastric solvent, by bringing each part successively into contact with the lining membrane of the stomach from the surface of which the fluid is effused.—The *removal of the matters already reduced or dissolved*, also, has a most important effect in facilitating the solution of the remainder. This removal is due in part to the absorption of the matters in a state of solution, into the blood-vessels of the walls of the stomach (§ 107); and in part to the successive escape of the reduced portions through the pyloric orifice (§ 83).—The importance of the previous state of *minute division* and *incorporation with aqueous fluid*, in promoting the action of the gastric solvent, has been already dwelt-on (§ 78).

94. Although the *Chyme*, or product of gastric digestion, which escapes through the pyloric orifice into the duodenum, contains much azotized matter in a state of actual *solution*, a considerable proportion of it is still only *reduced* and mechanically *suspended;* and the solution of the latter is continued in the intestinal tube. In the farinaceous part of the food, moreover, no great amount of change has hitherto been effected; and the sugar which has been generated by the agency of the salivary ferment, is probably absorbed into the blood-vessels nearly as fast as it is formed. In the condition of the fatty matters, no important change is perceptible, except such as results from the solution of the membranes, &c., that enclosed them. Hence we see that the process of Digestion, so far from being completed in the stomach, has only been carried one stage further. Soon after its entrance into the Duodenum, the chyme is subjected to the actions of the Bile, the Pancreatic fluid, and that secretion from the glandulæ in the walls of the intestine itself (proceeding chiefly, perhaps, from the glands of Brunner, § 98), which is known under the name of the 'Succus Entericus.'—Of these, the *Pancreatic* fluid will be first noticed. The structure of the Pancreas closely resembles that of the Salivary glands (§ 90); for it consists of racemose clusters of secreting follicles, which form the terminations of the ramifying divisions of the duct; each cluster, with its blood-vessels, lymphatics, nerves, and connecting tissue, forming a lobule; and the separate lobules being held-together by areolar tissue, as well as by the

vessels and ducts. Like the salivary glands, moreover, its development commences by a sort of budding-forth of the alimentary canal at a particular spot, upon which a mass of cells has previously accumulated. The secretion of this gland resembles saliva in its general appearance, being clear and colourless, free from smell, alkaline in its reaction, and very viscid. Upon the application of heat, or upon the addition of any of the stronger mineral acids, it coagulates in a solid mass like the white of an egg. Its properties seem to vary according to the period of digestion at which it is collected, being at first very tenacious and coagulating completely, whilst at a later period it becomes thinner, more alkaline, and less perfectly coagulable by heat its solvent powers upon various constituents of the food being, at the same time, less strongly marked. The composition of the Pancreatic Juice of the Dog is represented in the following Table.*

In 1000 Parts.	From a permanent Pancreatic Fistula. Mean of 3 Experiments.	From the Pancreatic Duct itself.	
		I.	II.
Water	980·45	900·76	884·4
Solid residue	19·55	99·24	115·6
Pancreatin	22·71	90·44	—
Salts	6·84	8·80	—
Soda combined with Pancreatin	3·31	0·58	—
Chloride of sodium	2·50	7·35	—
Chloride of potassium	0·93	0·02	—
Phosphate of lime	0·07	0·41	—
Phosphate of magnesia with traces of oxide of iron	0·01	0·12	—
Tribasic phosphate of soda	0·01	—	—
Lime combined with Pancreatin	—	0·32	—
Magnesia combined with Pancreatin	0·01	—	—

Leucine, Guanine, and Tyrosine, appear to be constant constituents of the substance of the gland, and Leucine has occasionally been found in the secretion. The nature of the organic substance which forms so large a part of the solid residue of the pancreatic juice, and which is so singularly prone to decomposition, has not been accurately determined. Bernard states that it resembles albumen in being precipitated by heat, acids, alcohol, and metallic salts, but differs in being thrown down by sulphate of magnesia, and by the circumstance, that, after being precipitated by alcohol, it can be redissolved in water. The quantity of the secretion which is poured forth in 24 hours, has been variously estimated; and perhaps the differences are due, as Bernard has suggested, to the circumstance that when the operation for the formation of a pancreatic fistula has been attended with much violence, when the gland has become inflamed, and the health of the animal has in consequence suffered, the fluid secreted is abnormal, and differs both in quantity and in many of its most essential properties from the healthy secretion. From these considerations, and from the probably intermittent character of the secretory act, it is manifest that only an approximative estimate of the absolute quantity can be made. Bernard estimates the quantity secreted per hour in the dog, for every 1 lb. weight of the animal, at about 15 grains; Schmidt and Kröger at from 20 to 35 grains.* A man weighing 160 lbs., at this rate would secrete 15 or 16 lbs. of pancreatic juice per diem! Bernard describes the gland as pale and flaccid during the period of fasting, and as rosy (but not deep red, Schiff†) some time after food has been taken, when the secretion is rapidly poured forth. The activity of the gland seems to be greatest at the middle or towards the close of gastric digestion‡, and at the period, therefore, of the passage of the contents of the stomach into the small intestine. As the organ is of considerable size, is very constant amongst the Vertebrata, and uniformly discharges its secretion into the duodenum, it is natural to suppose that it must exert an important influence in preparing the food for absorption; and this is fully borne out by our knowledge of the serious interference to the due performance of this operation, resulting from disease of this organ, and of the extreme instability of the organic matter contained in its secretion.—From the researches of many experimenters, it appears to be well ascertained—1. That the pancreatic juice can convert starch into sugar. 2. That it can emulsify fat. 3. That it can, to a certain and limited extent, dissolve albumen. The saccharifying influence of the pancreatic juice upon starch was first observed by Valentin, and may be proved by adding the healthy secretion obtained by a fistulous opening, or even an infusion of the gland-substance, to either crude or boiled starch; for though the energy of the action is much greater in the latter case, yet even in the former the starch-grains become rapidly altered in form, disintegrate, and dissolve; grape-sugar being at the same time produced. From Schmidt's experiments it appears, that one part of the secretion can convert about four-and-a-half parts of starch into grape-sugar.§ The necessity which exists for the conversion of starch into sugar, before it can be absorbed, renders evident the advantage which attends the presence of a gland possessing a similar transforming power to that of saliva, at some distance from the mouth, where it may act upon the crude starch now softened, swollen, and otherwise affected by the combined heat and moisture of the stomach, and which would otherwise escape being acted on. The pancreatic juice is not, however, exclusively destined for this function; sharing it with the 'succus entericus,' which has been shown by Frerichs and Hübennet, and especially in the interesting case recorded by Busch,* to be also possessed of this converting power.†—But secondly, it has been affirmed by M. Cl. Bernard, and strong evidence has been adduced by him in support of his statement, that the *essential* purpose of the Pancreatic fluid is to promote the absorption of fatty matters, by reducing them to the state of an *emulsion*, which is capable of finding its way into the lacteals. That this fluid possesses the emulsifying power in a peculiar degree, may be considered as having been fully demonstrated by his experiments; for on mixing it with oil, butter, or any variety of fat, at a temperature sufficiently high to render the fatty substance liquid, and then stirring the mixture for a few minutes, an emulsion is produced, bearing a strong resemblance to chyle. This emulsion does not cease to present its peculiar aspect, although left standing for some time; whereas although bile, saliva, gastric juice, blood-serum, and other animal fluids, have a certain emulsifying power, yet after a short time, the oil-particles run together again, almost as if they had been merely shaken-up with water. Further, it is asserted by Bernard, that in the Rabbit (in which the pancreatic duct discharges itself some inches lower down in the intestine than does the bile-duct), when fatty matters have been introduced into the alimentary canal, they undergo no considerable change, until they have passed the orifice of the pancreatic duct; an oily emulsion being then for the first time found in the intestinal canal, and the opaque whiteness of chyle showing itself in the contents of those absorbents only, which originate in the intestinal villi below that orifice. So, again, M. Bernard affirms that by putting a ligature round the pancreatic duct, the digestion of oleaginous matter is so completely prevented, that it is found unchanged in the lower part of the intestinal tube, and no opalescent chyle is found in the lacteals. This position is further strengthened by the fact ascertained by clinical observation,‡ that there is a close relation between disease of the pancreas, and the discharge of fatty matters per anum. Frerichs, Lehmann, Lenz,§ and others, endeavoured to show that the statements of M. Bernard were too exclusive in their character, and that the digestion and absorption of fatty matters took place after the pancreatic duct had been tied (sufficient time having been given for the evacuation of any pancreatic fluid that might have been in the alimentary canal previously to the operation), and even in the lower part of the small intestine, into which these substances had been conveyed by injection, after it had been completely separated by a ligature from the upper part into which the pancreatic fluid was poured. Bernard replied with great acumen to these observers, that after tying the duct they did not in most instances take care to ascertain whether a second duct was present or not, a circumstance of common occurrence in some animals; and secondly, that when the experiments were in other respects satisfactorily performed, the emulsification of the fats might still have been effected by the increased activity and development of certain glands which he has observed between the coats of the duodenum, in immediate proximity to the entrance of the duct of the pancreas, and the secretion of which he found to resemble very closely that of the pancreas itself. It must be observed, however, that Bérard has dissected out these glands, and ascertained that their collective weight does not exceed 1-325th that of the pancreas; and, therefore, the function of that gland can, in the first instance, at least, be but imperfectly discharged by them. Colin (of Alfort), moreover, made some ingenious experiments, in which he determined the quantity of fat contained in the chyle of cows and other animals, both before and after ligature of the pancreatic duct, and after extirpation of the gland.* He was unable to discover any remarkable difference in its composition. Similar experiments were made by Herbst, Schiff and Donders, from which the conclusion may be fairly drawn, that though the pancreatic juice is of considerable importance in the emulsification of fatty bodies, yet that its action is not indispensably requisite for their absorption; and it is possible, as Frerichs and Hubbenet state, that the Succus Entericus may possess an emulsifying power of considerable energy, and quite sufficient, in the absence of the pancreatic juice, to prepare a due amount of fat to supply the demands of nutrition. In Busch's case, however, already referred to, the digestive action of the fluid poured forth by the lower part of the Jejunum and Ileum upon fatty bodies introduced into them through the fistulous orifice, was exceedingly imperfect.—If the part played by the pancreatic fluid in the digestion of fatty bodies is still in some measure doubtful, its capability of effecting a solution and metamorphosis of albuminous bodies is still more difficult to determine. There appear to be three views in respect to this power: 1st, that of Corvisart, Schiff and Mitchell,† who are of opinion that healthy pancreatic juice, or the infusion of a healthy pancreas, or even a solution of the precipitated pancreatine in distilled water, possesses a distinctly solvent action on albumen, converting it into a peptone-like substance. 2ndly, the view supported by Keferstein, Hallwachs, Brinton, Funke and others, that though the pancreatic juice is certainly capable of effecting a solution of albumen, yet that this action only occurs with the supervention of putrefaction. 3rdly, the view entertained by Bernard, which certainly seems the most rational, that the solvent power of the pancreatic juice for albuminous substances is only exercised when it is mixed with bile, and then only after the preparatory action of the gastric juice. This is substantiated by the experiments of Skrebitzki and Bidder, which led to the conclusion that the pancreatic juice can, under some circumstances, dissolve albumen, converting them *without putrefaction* into peptone-like bodies. But to effect this two important conditions are requisite; namely, that the pancreatic juice should be obtained from an animal that was in the act of digesting its food; and secondly, that the solution should possess a

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* Gorup-Besanez, "Physiol. Chemie," 1862, p. 487.

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* See M. Edwards, "Leçons sur la Physiologie," 1860, p. 522. Colin obtained about 10 oz. per hour from a cow of medium size and from a horse, but only 3 drachms from a pig.

† "Wagner's Archiv," band iii., 1862, p. 271.

‡ Weinmann observed in a dog during the first hour after a full meal, 1510 grains secreted, whilst after a 45 hours' fast only 7¼ grains ("Henle and Pfeuffer's Zeitschrift," N. F. band iii., p. 247). Kröger obtained 384 grains during the 1st hour, 271 in the 2nd, 225 in the 3rd, 4th, 5th, and 6th, 176 in the 7th, 8th, and 9th, 165 from the 10th to the 14th, and 103 from the 19th to the 24th. Corvisart attributes the secretion to a kind of charging of the pancreas with albuminous compounds absorbed during digestion, for on the introduction of food, or of the products of gastric digestion below the entrance of the pancreatic duct, no increase in the flow of the secretion occurred ("Archiv. Gén. de Med.," i., 1861, p. 533).

§ In unhealthy conditions it is not unlikely that the same changes may take place, as occur when pancreatic juice is allowed to remain long upon starch-paste at a moderately high temperature; these changes being accompanied with the evolution of hydrogen, nitrogen, and carbonic acids, indicating the occurrence of the lactic, butyric, or even alcoholic fermentation.

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* "Virchow's Archiv f. path. Anat. und Physiol.," vol. xiv. p. 140.

† See also "Canstatt's Jahresbericht," 1862, p. 112.

‡ See Dr. Bright's researches on this point, in "Med.-Chir. Trans.," vol. xviii.; also an Article on Pancreatic Disease and Fatty Discharges, in "Brit. and For. Med.-Chir. Rev.," vol. xii. p. 154.

§ "De Adipis Concoctione et Absorptione," Dorpat, 1850.

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* "Compt. Rend.," 1856.

† "Amer. Journal of Med.," 1860.

weakly acid reaction.* These observers made infusions of the fresh pancreas of pigs, and found that they presented an acid reaction, which they considered might possibly be due to the acidification of the fatty substances unavoidably mingled with the proper juice. Pieces of albumen were gradually dissolved at a temp. of 100° Fahr., with the production of a strong broth-like odour. Before any action had taken place on the cubes of albumen, coagulation occurred on heating the fluid; but after digestion, no precipitation took place, though alcohol and tannic acid readily proved the presence of some peptone or similar substance; so that the digestive operation had not only acted on the albumen introduced, but also on the albuminous substances originally present in the infusion. The conclusion which seems naturally to follow from these premises is, that the alkaline pancreatic juice, as it issues from the gland, has but little action on albuminous compounds; but when it becomes slightly acid, either by incipient decomposition or by admixture with the gastric juice, it acquires the power of converting albumen, and that insoluble form of albumen called parapeptone, into the soluble peptone, and so effecting their solution.† In a remarkable and well-observed case of atrophy of the liver and pancreas described by Dr. J. A. Flés, a considerable quantity of fat and undigested muscular fibre was found to pass away in the fæces, but after the daily administration of a calf's pancreas nearly all the *fat* and a great proportion of the *muscular tissue* disappeared.‡

95. The Duodenum receives not only the Pancreatic, but also the *Biliary* secretion; and from the constancy with which this fluid is poured into the upper part of the intestinal tube, or even into the stomach itself, in all animals which have any kind of hepatic apparatus,§ it seems a legitimate inference that this secretion is not purely excrementitious, but serves some important purpose in the digestive process. It is not easy, however, to state with precision what this purpose is. The results of many of the experiments which have been made to determine it, are vitiated by the fact, that the pancreatic duct in most cases discharges itself into the intestinal tube at the same point with the hepatic, and has thus been frequently involved in operations performed upon it.—As the most important constituents of Bile, and the agency of the Liver as an assimilating and depurating organ, will be more appropriately considered elsewhere (CHAPS. IV. and IX.), we shall here limit ourselves to the consideration of what may be regarded as the best-established facts in regard to the uses of the biliary secretion in the digestive process.

96. When its action is tested out of the body, by mingling it with the different constituents of food, it is found to exert a slight action in converting starch into sugar.|| It has no action upon cane-sugar, until it has stood a considerable length of time; but then it converts it into lactic

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* Henle and Meissner's "Bericht," 1860.

† See Henle and Meissner's "Bericht," 1859, p. 238. Brinton in "Dublin Quarterly Journal," 1859, p. 194; and in "Medic.-Chir. Rev.," 1862, vol. ii., p. 203.—v. Gorup-Besanez, "Phys. Chem." p. 487. Schiff in "Canstatt's Jahresbericht," 1862, p. 132.

‡ "Donders' Archiv," 1862, Bd. iii. pt. ii., p. 187.

§ See "Princ. of Comp. Phys.," 4th Edit., §§ 405—411.—The simplest condition of the Liver, such as we meet with in the higher Radiata, and in the lower Articulata and Mollusca, consists in a series of follicles lodged in the walls of the stomach and of the upper part of the intestinal tube.

|| v. Gorup-Besanez, 1862, p. 467.

acid. This change it speedily exerts, as do nearly all other animal substances, upon grape-sugar. It has no action on albuminous substances, even when acidulated. And although it will form an emulsion with oleaginous matter, and especially with the fatty acids, yet the emulsification is less complete than that which is effected by the pancreatic fluid alone.[*] But if the action of the Bile is only subsidiary to that of the Pancreatic Juice, it is certain that it very materially aids the absorption of oleaginous bodies by enabling them to pass more easily through the coats of the intestine; Wistinghausen[†] and Hoffman[‡] having shown that the force requisite to effect the filtration of an oily substance through an animal membrane is much less when the membrane is moistened with an alkaline fluid, or with bile, than when it is moistened with pure water. Bile appears to be deficient in any materials corresponding to the peculiar ferments of the saliva, gastric juice, and pancreatic secretion; and hence its office in digestion must be of a different character from that of either of those fluids. The nature of this office may be partly judged-of, from what takes place when fresh bile is mingled with fresh gastric juice: a precipitation of the tauro and glycocholate of soda and of the colouring matter of the bile then taking place, the supernatant fluid still retaining the acid reaction of the gastric juice. Dr. Dalton has, however, shown[§] that this precipitation does not take place with chyme, or the product of gastric digestion, that is to say, with gastric juice holding albuminose or peptones in solution; and therefore that the gastric juice and bile are not really antagonistic to each other in the digestive process. The admixture of the bile with the chyme seems further to have the effect of checking destructive chemical changes in its composition. For M. Bernard found that when two similar pieces of meat had been immersed for three months, one in a bottle of gastric juice alone, and the other in a mixture of gastric juice and bile, a strong ammoniacal odour resulting from decomposition was emitted from the former, whilst the latter was pure and free from any smell whatever. And it was remarked by MM. Tiedemann and Gmelin (and also recently by Hoffmann), that when the bile was prevented from passing into the alimentary canal, the contents of the latter were more fœtid than usual. Moreover, it is found that the admixture of bile with fermenting substances checks the process of fermentation; and M. Bernard has shown by ingeniously-contrived experiments,[||] that this power is exerted also to some extent in the living body. Hence we can understand how the reflux of bile into the stomach should seriously interfere with the process of gastric digestion; and how, when there is a deficient secretion of bile, or more food is swallowed than the bile provided for it can act-upon, or the character of the biliary secretion itself has undergone any serious perversion, there should be much more than the normal amount of putrefactive fermentation, as is indicated by an evolution of flatus, and very frequently by diarrhœa. Further, the want of proper neutralization of the gastric fluid will cause the continuance of acidity in the contents of the intestinal canal, which in its turn induces a state of irritation of its mucous membrane, and a perversion of its secretions: and it is one of the beneficial results of 'alterative' medicines, employed to remedy this condition, that, by augmenting the secretion of bile, they tend to reproduce a state of neutrality in the contents of the alimentary canal. Schiff [*] and Budge[†] have shown that the bile produces energetic, and indeed almost tetanic spasms of the muscles, both voluntary and involuntary, when applied either to the tissue itself or to the nerves supplying it. Its importance, therefore, in maintaining the peristaltic action of the intestine is probably considerable, whilst by exciting the involuntary muscular fibre-cells of the villi it very probably materially aids the movement of the chyle in the lacteals. Moreover, the presence of a proper quantity of bile in the intestine seems to promote the secreting action of the intestinal glandulæ; this appears from the tendency to constipation which is usually consequent upon deficiency of the secretion, and from the diarrhœa which proceeds from its excess; and is confirmed by the purgative properties which inspissated ox-gall has been found to possess.

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[*] Dr. Bence Jones, in the "Medical Times," July 5, 1851.

[†] "Endosmotisch Versuche," dissert. inaug., Dorpat, 1851.

[‡] "Über die Aufnahme von Quecksilber," 1854, Wurtzburg.

[§] "Phys.," 1861, p. 176.

[||] "Amer. Journ. of Med. Sci.," Oct. 1851, p. 351.

97. Notwithstanding all its uses, however, it must be admitted that the prevention of the discharge of bile into the alimentary canal is not attended with the deleterious results which might have been anticipated from it; for it has been found by the experiments of Schwann, Blondlot, and Bernard, that if the bile-duct be divided, and a tube be inserted in it in such a manner as to convey-away the secretion through a fistulous orifice in the abdominal parietes, the animals thus treated may live for weeks, months, or even years,[‡] although they usually die at last with signs of inanition. Of the quantity of bile daily poured into the alimentary canal of Man, we have no other mode of forming an estimate, than by observing the quantity poured-out from the bile-ducts of animals in such experiments as those just cited. Nasse and Platner[§] obtained from a dog 105 grains, and Stackman 108 grains per diem, for every 1 lb. of body-weight. On these data a man weighing 154 lbs. should form about 2½ lbs. of bile daily. Bidder and Schmidt give a somewhat higher estimate, viz. 56 oz. or 3½ lbs., of which they consider about 5 per cent. to be solid matter.—It appears from the researches of numerous investigators that the rate of secretion is by no means uniform. Arnold[‖] found that it attained its maximum an hour or two after food, Voit[¶] two hours after, Kolliker and Muller between the 6th and 8th hours, and Bidder and Schmidt[**] about 10 or 12 hours after a full meal.—As Dr. Dalton has remarked, a distinction should be drawn between the time at which the largest quantity of bile is discharged into the intestine, and that at which the secretory activity of the liver is at its height. In his own experiments, which appear to have been conducted with much care, a con-

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[*] "Archiv für Phys. Heilk.," t. ix., p. 60.

[†] "Physiologie," p. 195, 1861.

[‡] At the meeting of the French Academy, June 23, 1851, M. Blondlot gave the history, and an account of the post-mortem examination, of a dog that had lived five years without the passage of any bile into the intestinal tube.

[§] Béclard's "Physiol.," 1802, p. 501.

[‖] "Zur Phys. der Galle," Mannheim, 1854.

[¶] "Phys. Chem. Untersuchungen," Augsburg, 1857, p. 41.

[**] "Verdauungssäfte und Stoffwechsel," §§ 114—209.

siderable quantity of bile was discharged into the intestine soon after feeding, as is shown in the following table:*—

Time after feeding.	Quantity of fluid in 15 minutes.	Dry residue of the same.	Quantity of biliary matter.	Proportion of biliary matter to dry residue.
Immediately	640 grains.	33 grains.	10 grains.	.30
1 Hour	1990 ,,	105 ,,	4 ,,	.03
3 ,,	780 ,,	60 ,,	4 ,,	.07
6 ,,	750 ,,	73 ,,	3½ ,,	.05
9 ,,	860 ,,	78 ,,	4½ ,,	.06
12 ,,	325 ,,	23 ,,	3¾ ,,	.16
15 ,,	347 ,,	18 ,,	4 ,,	.22
18 ,,	—	—	—	—
21 ,,	384 ,,	11 ,,	1 ,,	.09
24 ,,	163 ,,	9½ ,,	3¼ ,,	.34
25 ,,	151 ,,	5 ,,	3 ,,	.60

The secretion diminishes considerably when food is withheld for some time; the quantity poured-out after ten days' starvation being only about one-eighth of what it is when at its maximum. Still it is obvious, that although its rate is thus greatly influenced by the stage of the digestive process (which is the less to be wondered-at, when it is remembered that the secretion is formed from blood that is charged with newly-absorbed and imperfectly-assimilated matters), the excrementitious character of the secretion requires that its elimination shall be constantly going-on to a certain degree; but a receptacle is provided in Man, as in most others among the higher animals whose digestion is performed at intervals, for the storing-up of the fluid until it can be usefully employed in that process. The intestinal orifice of the ductus choledochus is closed by a sort of sphincter; and the fluid secreted during the intervals of digestion, not being propelled with a force sufficient to dilate this, flows back into the gall-bladder, which dilates to receive it. The presence of food, and especially of the acid products† of gastric digestion, in the duodenum seems to excite the walls of the gall-bladder and of the biliary ducts (which contain a large quantity of non-striated muscular fibre), to a contraction sufficiently powerful to propel their contents into the intestine, in spite of the opposition of the sphincter; but whether this takes place through a reflex action of the nervous system, or through the direct stimulation of the muscular coat of the duct by the passage of alimentary matters over its orifice, we have at present no means of satisfactorily determining. It will be recollected that the gall-bladder is usually found distended with bile, in cases of death from starvation (§ 59), notwithstanding the diminution in the amount actually secreted. Of the bile which is poured into the intestinal tube, by far the greater proportion seems to be re-absorbed (§ 103).

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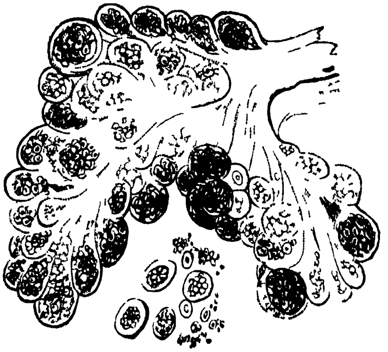
* Dalton, "Phys.," 1861, p. 174.—The dog used for these experiments weighed 36½ lbs.

† Bernard and Küthe ("Canstatt's Jahresbericht," 1861, p. 131) found that touching the point of entrance of the biliary duct into the intestine with an alkaline fluid had little or no effect, whilst brushing it lightly over with an acid solution immediately caused a discharge of bile to take place.

FIG. 17.



Portion of one of *Brunner's Glands*, from the Human Duodenum.

98. Besides the biliary and pancreatic secretions, there is poured into the upper part of the Intestinal canal a fluid secreted in its own walls, which has received the designation of *Succus Entericus.* It seems not improbable that the secretion of this fluid may be the function of the Glands of Brunner, which are small racemose clusters of follicles (Fig. 17), imbedded in the walls of the duodenum, extending also to the commencement of the jejunum. The Intestinal juice appears, from the researches of Bidder and Schmidt,* to be a colourless viscid liquid, invariably alkaline in its reaction, and containing from 3 to 3½ per cent of solid matter. The total amount daily secreted in Man is estimated by these experimenters at about 7 oz.; the rate of its secretion seems to be most rapid five or six hours after a meal; and its quantity is considerably increased shortly after the ingestion of fluid, and this without any diminution in the proportion of its solid constituents. The properties of this secretion are extremely remarkable; for according to the results obtained by Bidder and Schmidt and their pupil Zander (which are now admitted by Lehmann), it exerts a solvent action on albuminous bodies scarcely inferior to that of the gastric juice, and a power of converting starch into sugar which is scarcely less than that of saliva or pancreatic fluid.—In an experiment of Frerichs, referred to by Donders,† a loop of intestine was ligatured and reintroduced into the abdomen. After a few hours it was found to contain a tenacious alkaline mucus, in which no albumen was present, as neither Alcohol, Tannic Acid, nor Metallic Salts occasioned any precipitate. Busch, who obtained an analogous fluid directly from the human subject in health, found it to contain 5·47 per cent of solid residue; and though small in quantity, it was capable of being considerably increased by mechanical irritation.

99. The fluid of the Small Intestines, which is compounded by the intermixture of the biliary and pancreatic secretions with the salivary and gastric fluids, and with the secretion of the intestinal glandulæ, appears to possess the very peculiar power of dissolving, or of reducing to an absorbable condition, alimentary substances of every class; thus possessing more of the character of a 'universal solvent,' than either of these secretions has in its separate state. It completes the conversion of starchy into saccharine matter; and thus enables the former to supply the blood with an important pabulum for the combustive process, which is at once absorbed into the blood-vessels. It emulsifies the oleaginous

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* Op. cit., §§ 260—282; and Lehmann's "Physiologischen Chemie," 2nd Edit., band ii., pp. 95—99.

† "Phys." 1859, p. 237.

matter, and thus renders it capable of being introduced into the lacteals. And it not only restores to the state of solution those albuminous compounds which may have been precipitated by the addition of bile to the product of gastric digestion; but it also exerts a powerful solvent influence upon albuminous substances which have not been submitted to the previous agency of the gastric fluid (as has been shown by experimentally introducing pieces of meat, through a fistulous orifice, directly into the duodenum), and it thus completes the solvent process which had been very far from perfected in the stomach.* In Busch's interesting case, in which the contents of the stomach and duodenum were completely prevented by a fistulous opening from entering the small intestine, it was clearly determined by accurate chemical analysis of the fæces, as well as indicated by the great improvement in the health which resulted from introducing food into the lower part of the intestine, that the fluids secreted by the jejunum, ileum and large intestine were capable of dissolving albumen (though with the evolution of a putrefactive odour, probably due to the absence of the bile) and of converting starch into sugar. There seemed, however, to be little or no emulsifying power exerted on the fats, which were also but very slightly absorbed, the greater part reappearing in the fæces. In this case the woman lived for six weeks, previous to her coming under the care of M. Busch, upon the absorption which had taken place in the stomach and duodenum. A great portion of the products of digestion flowed off by the fistulous orifice, and she had become much emaciated. The treatment adopted was the reintroduction of this discharged fluid into the lower orifice of the fistulous opening, and she rapidly regained her health and strength. What is the precise share, however, of the various secretions, in producing this composite result, cannot be stated with any degree of certainty.—It is obvious that the amount of each kind of alimentary substance that can be thus prepared for absorption in a given time, will vary with the amount of the secretion by whose agency this preparation is specially affected; and as there are many indications that the quantity of each that is taken-up in absorption is limited, and that it bears a relation to the wants of the system, it is probable that the amount of the solvent or reducing fluid secreted by each glandular apparatus, is regulated (as we have seen it to be in the case of the gastric juice (§ 87) by the demand set-up by the nutrient operations, rather than by the amount of alimentary matter that is waiting to be digested.—The processes of digestion and conversion are probably continued during the entire transit of the alimentary matter along the small intestine, and at the same time the products of that conversion are gradually being withdrawn by absorbent action; so that, by the time it reaches the cæcum, the undigested residue contains little else than the innutritious or insoluble components of the food, together with the excrementitious portion of the bile and of other secretions. Up to this time the contents of the canal appear to possess an acid reaction; for in an old person, with an artificial anus opening into the lower part of the ileum, examined by Dr. Braun,† the chyme was still acid, though the mucous membrane was alkaline to test-paper. In the cæcum, however, the acidity seems to become still more marked, at least in the Herbivora, owing to the formation of lactic acid from the starchy materials of the food;[*] but in Carnivora, according to Bernard,[†] the contents of the cæcum are alkaline, owing to nitrogenous fermentation. That digestion will still take place, though imperfectly, in the large intestine, is shown by the observations of Steinhauser [‡] upon a woman who had an artificial anus communicating with the large intestine. When food was introduced into the lower part of the bowel, it was for the most part discharged unaltered; but albumen was to some extent dissolved, either, as Blondlot conceives, from the presence of lactic acid, or possibly from that of butyric and acetic acids. This fact is of importance, as showing the mode in which injections of nutrient substances per anum act in prolonging life in cases where the passage of food along the upper part of the intestinal tube is interrupted.

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* See the account of M. Cl. Bernard's researches in the "Amer. Journ. of Med. Sci.," Oct. 1851, p. 356; Zander, "De Succo Enterico," inaug. diss., Dorpat, 1850; and Frerichs, art. *Verdauung*, in "Wagner's Handwörterbuch," band iii.

† "Archiv. Gén. de Médecine," 1861, p. 610.

100. The Intestinal tube is furnished, throughout its entire length, with innumerable simple open glandulæ, the 'follicles of Lieberkühn;' these are straight narrow cæca, standing side by side, with very little intervening substance (except where the Peyerian bodies lie amongst them), and corresponding in length with the thickness of the mucous membrane. Their orifices are seen in the interspaces between the villi, where they are so closely set-together as to seem like the apertures of a sieve; and they are arranged in rings around the Peyerian glandulæ. The precise nature of their secretion is unknown; and it seems not improbable that notwithstanding the close resemblance which they bear to one another in anatomical characters, there may be some variety of function among them.

101. The undigested residue of the food, mingled with the products of secretion that have been poured into the alimentary canal, gradually acquires, in the large intestine, the ordinary consistency of Fæces, through the continuance of the absorbent process, whereby the superfluous fluid is removed. The condition of this residue has been particularly studied by Dr. Rawitz and Dr. Marcet.[§] By the former observer, muscular fibres are stated to be almost entirely dissolved, especially in the flesh of fish and hares, though less rapidly in that of poultry and other animals, only a few fragments remaining. Dr. Marcet, however, found muscular fibres, exhibiting clearly their well-marked structure, almost constantly present and in considerable quantities; and he is inclined to believe that when meat is daily taken, only the juices are extracted, the fibres themselves undergoing but little digestive action. The cells of cartilage and fibro-cartilage, the fibres of elastic tissue,[‖] and fatty matter, are frequently

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[*] Blondlot, "Traité analytique de la Digestion," p. 103.

[†] "Liquids of the Organism," p. 39, 1859.

[‡] Quoted in Milne-Edwards, vol. vii. p. 136, 1862.

[§] "Med. Times and Gaz.," July 31, 1858.

[‖] It has been pointed-out to the Author by his friend Mr. Quekett, that elastic fibres are occasionally to be met-with in the Human fæces, which present an appearance of transverse division (probably resulting from incipient decomposition) closely resembling that which is normal in the ligamentum nuchæ of the Giraffe. So distinct, indeed, does the transverse division then become, that these fibres, when peculiarly abundant (as they are in the fæces of persons who have for some time been living upon mutton-chops, and have not put aside the segment of the aorta which each chop includes), have actually been mistaken for a Confervoid growth in the fæces.

found unchanged in the fæces; and crystals of cholesterin may usually be obtained, especially after the use of pork-fat.—"As regards *vegetable* substances, Dr. Rawitz states that he frequently found large quantities of cell-membranes unchanged in the fæces; also starch-cells (which were rarely seen by Dr. Marcet), deprived of only part of their contents. The green colouring principle, chlorophyll, was usually unchanged. The walls of the sap-vessels and spiral vessels were quite unaltered by the digestive fluid, and were usually found in large quantities in the fæces; their contents, probably, were removed."*—Besides the undigested residue of the food, the microscope enables us to recognize the brown colouring-matter of the bile, epithelium-cells and mucus-corpuscles, and various saline particles, especially those of the ammoniaco-magnesian phosphate,† whose crystals are well-defined; most of which are derived from the secretions. —The quantity of fæcal discharge which is daily passed by an adult seems to vary from 2 to 10 oz. Dr. Edward Smith found the average weight in prisoners at the Coldbath Fields Prison to be 8.55 oz. These men were fed upon a full dietary with brown bread, and the proportion of the fæces to the solid food was as 1 : 4.5. Severe labour on the treadmill was found to diminish the quantity of fæces, whilst the rest of Sunday occasioned a considerable increase. The proportion of water was very uniform, viz. 73.5 per cent; and an average of 41.8 grains of nitrogen was daily eliminated from the system by this channel.‡ Of the dry fæces, from 23 to 31.5 per cent (the proportion being highest when an abundant meat diet has been consumed) consists of an Inorganic ash; the composition of which is stated by Enderlin§ to be as follows:—

Alkaline chlorides and sulphates	1.367	Soluble in water
Bibasic phosphate of soda	2.633	
Phosphates of lime and magnesia	80.372	Insoluble in water.
Phosphate of iron	2.090	
Sulphate of lime	4.530	
Silica	7.940	

The potash generally predominates greatly over the soda, but especially when the diet has chiefly consisted of muscular flesh. The reaction of the Fæces is usually acid, but sometimes neutral or alkaline. The study of the composition of the Organic portion of the Fæces is attended with so much difficulty and unpleasantness, that it has hitherto been scarcely prosecuted systematically. According to the recent inquiries of Dr. Marcet,‖ healthy Human excrements contain,—1. A peculiar substance crystallizing in acicular, silky, four-sided prisms usually grouped into stellæ, not subject to spontaneous decomposition, possessing feeble affinities, fusing at

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[*] Quoted from Dr. Kirkes' "Physiology." See also the Memoir of Dr. Rawitz, "Über die Einfachen Nahrungsmittel," Breslau, 1846; and the Analysis of Wehsarg and Ihring's Inaugural Theses in "Brit. and For. Med. Chir. Review," vol. xiv. p. 528.

[†] Crystals of this salt sometimes occur in perfectly normal fæces; and in those cases in which the secreted fluids and the contents of the intestine readily undergo decomposition, as in typhus, cholera, and certain forms of dysentery, they are found in large numbers and of considerable size.

[‡] Smith and Milner, 'Rep. on the Influence of Pris. Discip.' "Syd. Soc. Year-Book," 1861, p. 83.

[§] "Ann. der Chem. und Pharm.," 1844. Porter in do., t. lxxi.; and Fleischmann in "Poggendorff's Annalen," 1849.

[‖] "Proceedings of the Royal Society," June 15, 1854, and March 12, 1857.

about 203° F., containing Sulphur, and having a composition expressed by the formula $C_{78}H_{78}S_1O_2$; this he proposes to call Excretine. 2. Stearic and Margaric Acids in combination with bases. 3. A colouring matter similar to that of blood and urine. 4. Pancreatine or an analogous form of albumen. 5. An acid olive-coloured substance of a fatty nature, termed *Excretolic* acid, which is probably united in fæces with Excretine or a basic substance closely allied to it. Neither butyric nor lactic acid could be discovered in healthy Human excrement; although the former presents itself in the excrements of Carnivorous Mammalia, which contain also a substance allied in its nature to excretine, but not identical with it.

102. Planer* has recently examined the Gases developed in the alimentary canal of Dogs after different kinds of food, and in Man after death. The gas contained in the stomach consists chiefly of air swallowed with the food, and was usually small in quantity. The Oxygen soon disappeared. In the small intestines, Carbonic Acid and Hydrogen are developed in nearly equal proportion, whether the diet be Animal or Vegetable. The experiments of Pasteur† afford some explanation of their appearance, at least in Herbivora, by showing that with the development of numerous infusory animalculæ in the intestines, Starch and Sugar are converted into Lactic and Butyric Acids, and that with the development of the latter there is an evolution of Carbonic Acid and Hydrogen: thus—one equivalent of Sugar $C_{12}H_{12}O_{12} = (C_8H_7O_3)\ HO + 4CO_2 + {}_4H$. In the large intestine Carbonic Acid is chiefly present, but is mingled with Sulphuretted Hydrogen (after Animal diet), and if the food have been long retained in the body, with Carburetted Hydrogen (C_2H_4). It is more than doubtful whether Gases can be disengaged from the blood, and excreted or secreted into the intestines, as Magendie supposed; but there seems no reason to doubt that if gas were already developed, exchange, according to the ordinary laws of diffusion, might take place between it and the gases of the blood. In a dog which had been fed for 6 days on pure Animal diet, and was killed 5 hours after a meal, he found—

	CO_2.	O.	N.	H.	SH.
In the Stomach	25·20	6·12	68·68		
Small Intestine.	40·1	Traces	45·52	13·86	
Large Intestine.	74·19	0·63	23	1·41	0·77

In another dog fed with Bread for 8 days, there was only sufficient gas for analysis in the small intestine; it consisted of—

CO_2.	O.	N.	H.
38·78	Traces	54·2	6·33

Ruge‡ has carefully examined the Gases of the large intestine in the Human subject after different kinds of food, and finds their composition tolerably constant,—Nitrogen Gas preponderating after the use of flesh,

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[*] Henle and Meissner's "Bericht für 1860," p. 274.

[†] "Annales de Chimie," 1858, p. 404 *et seq.*; "Comptes Rendus de l'Académie des Sciences," 1860, p. 849.

[‡] "Beiträge zur Kenntniss der Darm Gase Sitzungsbericht d. k. Akad. d. Wissenschaften" (Wien), 1862, p. 729.

Hydrogen after milk, and Carburetted Hydrogen after Vegetable (Leguminous) diet. Though the gases were sometimes offensive, they never gave more than a trace of Sulphuretted Hydrogen. The following table includes his chief results :—

Composition of the Gases of the large Intestine after the use

	Of Milk, for		Of Vegetables (Leguminous), for					Of Animal Diet, for		
	1	2								
	48 hours.	72 hours.	48 hours.	72 hours.	96 hours.	2nd series of Experiments on same person.		24 hours.	48 hours.	72 hours.
CO_2	16·82	9·06	34·00	38·40	21·05	35·43	17·6	13·62	12·46	8·45
N	38·38	36·71	19·11	10·67	18·96	21·78	32·2	45·96	57·85	64·41
CH	0·92	0·00	44·55	49·36	55·96	42·79	50·2	37·41	27·58	26·45
H	43·88	54·22	2·34	1·67	4·03	0·00	0·0	3·01	2·09	0·69

103. Of the degrees in which the Bile, as a whole, normally enters into the composition of the fæces, it is difficult to speak with precision. Its principal constituents can be easily recognized in the upper part of the small intestine; but the further we descend in the intestinal canal, the less of them do we meet-with; and in the contents of the large intestine, and in the evacuated fæces, they are seldom to be discovered. How far this result depends upon their removal from the alimentary canal by re-absorption, and how far upon the loss of their characteristic properties by decomposition, cannot be stated with certainty. That the colouring-matter of the fæces is in great part derived from the bile, is shown by their paleness when that secretion is not duly poured into the intestinal tube. And it is probable that the peculiar fatty substances just described, are products of the metamorphosis of its oleaginous and resinous matters. The similarity which has been found to exist between the odour of certain components of putrefying bile, and that of fæces, has led Prof. Valentin to suppose that the matter which gives to the latter their characteristic smell, is entirely derived from decomposing bile. We shall presently see, however, that other sources of this matter probably exist (§ 104); and the recent researches of Bidder and Schmidt upon the amount of *sulphur* in the fæces, appear to show that not above one-eighth of the solid matter of the bile is normally excreted under this form. The indications of the presence of bile are more distinct, however, when the fæces have remained for only a short time in the large intestine, and when there has consequently been less time for its re-absorption. In fæcal discharges which result from the action of mercurials, large quantities of biliary matter may be detected, very little changed.

104. Although it cannot be stated with certainty, what is the precise portion of the Glandular apparatus connected with the Intestinal canal, which is concerned in the elimination of that peculiarly putrescent matter which gives to the fæces their characteristic odour, yet it may be stated almost with certainty, that this matter is *not* derived from the decomposition of the undigested residue of the food. For, in the first

place, this residue consists of matters whose very inaptitude for undergoing chemical change is the source of their indigestibility: and it is scarcely possible, therefore, to imagine that in so short a period they should acquire a character so peculiarly offensive. But further, we observe that fæcal matter is still discharged, even in considerable quantities, long after the intestinal tube has been completely emptied of its alimentary contents. We see this in the course of many diseases, when food is not taken for several days, during which time the bowels have been completely emptied of their previous contents by repeated evacuations. Sometimes a copious flux of putrescent matter continues to take place spontaneously; whilst it is often produced by the agency of purgative medicine. The "colliquative diarrhœa," which frequently comes-on at the close of exhausting diseases, and which usually precedes death by starvation, appears to depend, not so much upon a disordered state of the secreting organs themselves, as upon the general disintegration of the solids of the body, which calls them into extraordinary activity for the purpose of separating the decomposing matter which has accumulated in it to a most unusual amount (§ 60).—These views (which have long been taught by the Author) derive a remarkable confirmation from the experiments of Prof. Liebig on the production of artificial fæcal matter. For he has ascertained that if albuminous or gelatinous compounds be heated with solid hydrate of potash, and the heat be continued until the greater part or the whole of the nitrogen has been dissipated as ammonia, and hydrogen begins to be given-off, the residue, when supersaturated with dilute sulphuric acid, and distilled, yields a liquid containing acetic and butyric acids, and possessing in a very intense degree the peculiar and characteristic odour of human fæces. The odour varies according to the substance employed; and in this way all varieties of fæcal smell may be obtained. As the action of caustic potash at a high temperature is simply a limited or incomplete oxidation or combustion, this curious result confirms the view which had been previously put-forth by Prof. Liebig, that the proper fæcal matter is the product of the imperfect oxidation which a portion of the histogenetic constituents of the food undergo in the course of their retrograde metamorphosis, being comparable to the soot or lamp-black of a furnace or lamp. It is further urged by him, that the condition of fæces differs in many particulars from that of substances in a state of fermentation or putrefaction; that their peculiar odour is entirely unlike any that is generated by the ordinary decomposition of organic compounds, whether azotized or non-azotized; and that, by contact with air, they themselves undergo a sort of fermentation or putrefaction, in which their peculiar fœtor disappears, —a fact, as he justly remarks, which is full of significance.* This view is of great practical importance; for if it be true that the intestinal canal receives and discharges the products of the secreting action of a glandular apparatus, whose special function is the elimination of certain products of decomposition from the blood, the facility with which we can stimulate this to increased action by certain kinds of purgative medicine, gives us a most valuable means of augmenting its depurative action. Seeing, as no observant Medical Practitioner can avoid doing, how frequently Nature herself employs this means of eliminating morbific matter from the system,—as is shown by the immense relief often given by an attack of diarrhœa,—we may look upon this apparatus as one which, like the Liver, the Kidney, or the Skin, may frequently with propriety be stimulated by medicines that have a special action upon it, and one through which some morbific matters may be got rid of more certainly and more speedily than through any other channel.—It is not intended by these observations to encourage the system of violent and indiscriminate purgation; but to show that purgatives, judiciously administered, often constitute our best means of eliminating injurious matters from the system.

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* See Prof. Liebig's "Animal Chemistry," 3rd edit. pp. 148—154.

CHAPTER IV.

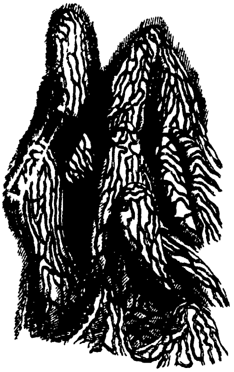
OF ABSORPTION AND SANGUIFICATION.

1. *Of Absorption from the Digestive Cavity.*

105. So long as the Alimentary matter remains in the Digestive cavity, however perfect may be its state of preparation, it is as far from being conducive to the nutrition of the system, as if it were in contact with the external surface. It is only when absorbed into the vessels, and carried by the circulating current through the very substance of the body, that it becomes capable of being appropriated by its various tissues and organs. In Man, as in nearly all Vertebrated animals, a set of vessels is interposed between the walls of the intestine and the sanguiferous system; for the purpose, as it would seem, of taking-up certain components of the nutritive matter, of which part at least are not in a state of perfect solution, and of preparing them for being introduced into the current of the blood. These are the *Absorbents* of the intestinal walls; of which those that are found, after the performance of the digestive process, to contain the white opalescent fluid known as 'chyle,' are distinguished as *lacteals;* while the remainder, like the absorbents of the system generally, are known as *lymphatics.* The distinction is a purely artificial one; for the 'lacteals' are the 'lymphatics' of those parts of the intestinal walls which they supply, as is shown by the fact that, during the intervals of the digestive process, they contain a transparent fluid in all respects similar to the 'lymph' of other parts.—The Absorbents form a minute plexus beneath the mucous lining of the alimentary canal along its whole extent; but in the small intestine they enter the villi, at the extremities of which, indeed, they may be said to commence. Those only are entitled to the designation of 'lacteals,' which originate from the intestinal canal below the point at which the biliary and pancreatic ducts pour their contents into it; for above that point, the fatty constituents of the alimentary matter are not in a state of sufficiently fine division to enter them; and the absorbed fluid is consequently pellucid, instead of possessing the milky aspect. Thus, then, we are to consider the *lacteal* portion of the Absorbent system to be that part of it which is specially adapted, by its prolongation into the villi, for the reception of an Oleaginous fluid; which we shall presently see to be taken-up from the contents of the alimentary canal, and to be prepared for entrance into the absorbents, by the epithelium-cells at the radical extremities of those organs (§ 106).

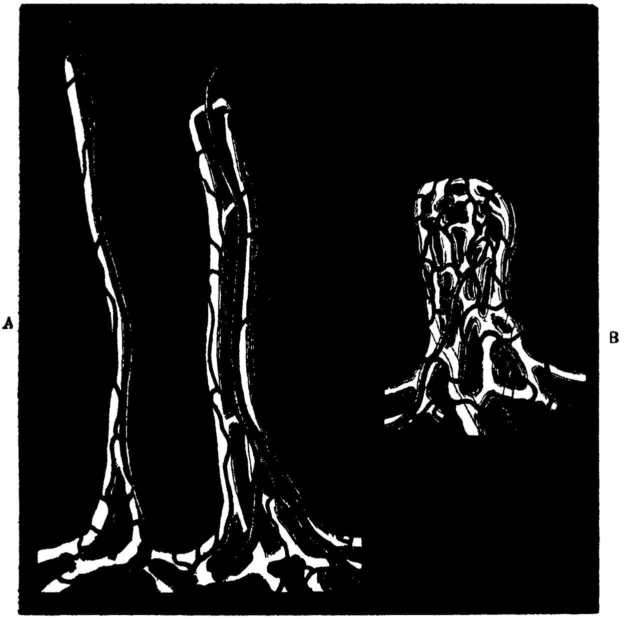
106. The *Villi* are extensions of the mucous lining of the Intestinal canal, which thickly beset its surface from the pyloric orifice to the cæcum, that is, through the entire length of the Small Intestine, to which they are limited in Man. They have usually somewhat the form of the finger of a glove, being sometimes nearly cylindrical, sometimes rather conical, whilst they not unfrequently become flattened and extended at the base, so that two or more coalesce. Their length varies from 1-4th to 1-3rd of a line, or even more; and the broad flattened kinds are about 1-6th to 1-8th of a line in breadth.—In the upper part of the small intestine, where they are most numerous, it has been calculated by Krause that there are not less than from 50 to 90 in a square line; and in the lower part, from 40 to 70 in the same area.—The details of their structure are of extreme interest in reference to the mechanism of absorption. If the plan pursued by Teichmann, that of injection, be adopted, the appearances presented are those shown in Fig. 19, 20, and 21, taken from the beautiful plates which accompany his work on the Lymphatic System.* From these

Fig. 18.



Villi of the Human Intestine, with their capillary plexus injected.

Fig. 19.



A. Villi of Man, showing the blood-vessels and the lacteals.
B. Villus of a Sheep.

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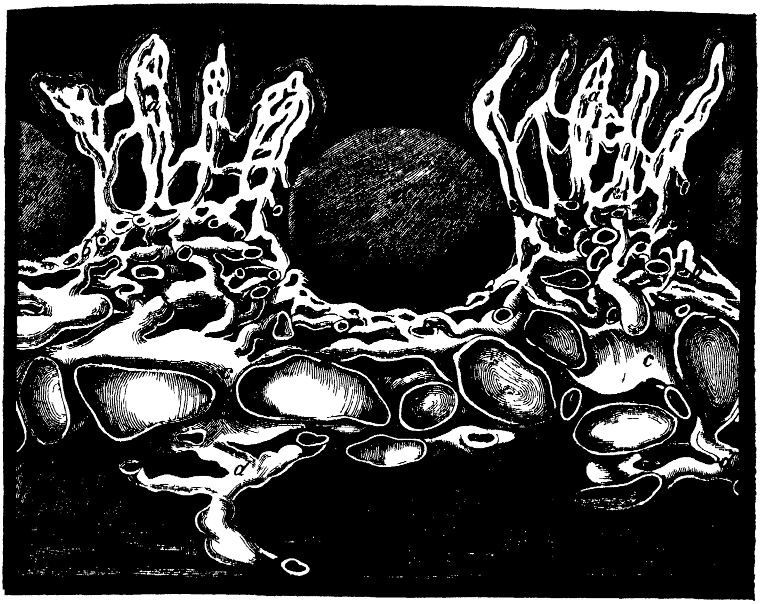
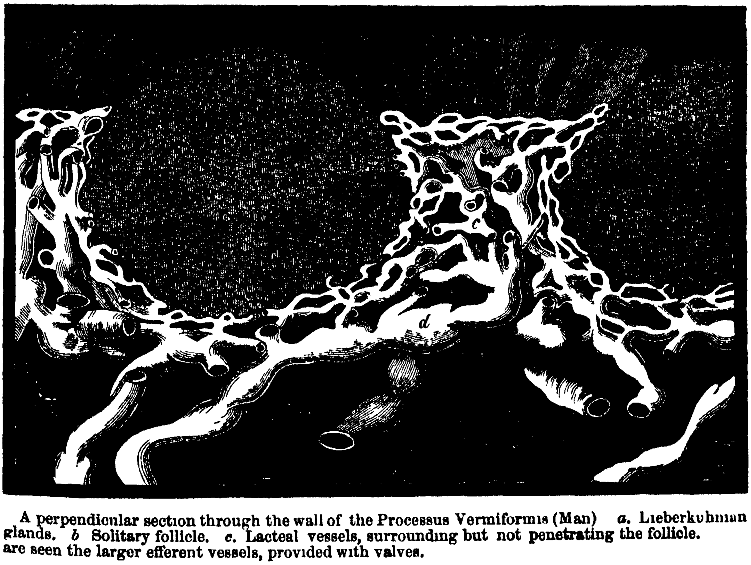
* Ludwig Teichmann, "Das Saugader System," Leipzig, 1861.

FIG. 20.



Perpendicular section through one of Peyer's patches in the lower part of the ileum of the Sheep *a*. Lacteal vessels in the villi. *b* The superficial layer of the lacteal vessels (rete angustum) *c* The deep layer of the lacteals (rete amplum) *d* Efferent vessels, provided with valves. *e*. Lieberkuhn's glands *f* Peyer's glands. *g* Circular muscular layer of the wall of the intestine. *h*. Longitudinal muscular layer. *i*. Peritoneal layer.

FIG. 21.



A perpendicular section through the wall of the Processus Vermiformis (Man) *a*. Lieberkuhnian glands. *b* Solitary follicle. *c*. Lacteal vessels, surrounding but not penetrating the follicle. are seen the larger efferent vessels, provided with valves.

it appears that the lacteals commence either by a simple closed extremity, or by a loop, though in broad villi a network is sometimes visible. The tube or tubes occupying the centre of the villus appear to possess perfectly definite walls, and are larger than the numerous capillary blood-vessels which surround and are external to them. Their average diameter is about 1-800th or 1-1000th of an inch; but they present here and there slight dilatations and contractions, and at the base of the villus terminate in a network of lacteal vessels immediately subjacent to the Lieberkühnian follicles (Fig. 20 *b*), termed by Teichmann, from the closeness of the meshes, the *Rete angustum.* This plexus communicates with another possessing larger vessels, which are supplied with valves, are more deeply situated in the submucous areolar tissue (Fig. 20 *c*), and constitute the so-called *Rete amplum.* Besides the central lacteal, the villus is composed of a matrix of areolar tissue,* without any intermixture of elastic fibres, containing in its interstices numerous branched and communicating cells with nuclei, and frequently also fat-granules in their interior. No nervous elements have been traced into the villi; but a layer of muscular fibre-cells has been shown by Kölliker and others to surround the lacteal tubes, the contraction of which has been frequently observed whilst absorption is going on, and has an important influence on the propulsion of the fluids contained within those vessels.

107. When the Villi are examined at such a period after a meal containing oleaginous matters as has sufficed for its partial digestion, their lacteals are seen to be turgid with chyle, the extremity of each being imbedded in a collection of globules presenting an opalescent appearance, and giving to the end of the villus a somewhat mulberry-like form. It was supposed by Prof. Goodsir,† by whom this appearance was first observed, that these globules were cells developed within the basement-membrane during the act of absorption, from what he considered to be granular germs visible in the same situation during the intervals of the process; but there can now be little doubt that the appearance in question is really due to the distension of the cylindrical epithelial cells *investing* the villi with the lacteal fluid; and as it is a matter of much interest to examine and explain the mode in which absorption in this, its first stage, is effected, the attention of many observers has been directed to the structure of these cylindrical investing epithelial cells; and if the observations of Heidenhain and Brücke be correct, our knowledge of the mode of absorption of various substances, and especially of those of an oleaginous nature, will be materially simplified. According to these investigations,‡ the investing cells of the villi (*c*, Fig. 22) are of cylindrical form, with a ciliated border, and are filled with a clear sarcode containing a bright nucleus. The cilia stand erect during life, but quickly disappear after death, being replaced by a globular swelling projecting from the mouth of the cell, occasioned by the imbibition of water. The wide and free extremity of these cells is supposed by some (Brücke) to be almost or completely patent, or closed only by a plug of sarcode-like substance, whilst Funke § and others

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* Kölliker, "Manual of Hum. Histology," p. 325.

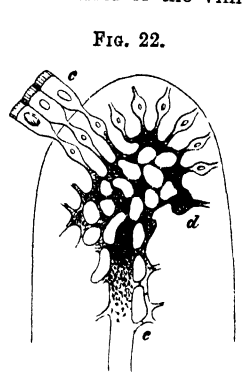
† "Edin. New Phil. Journ.," July 1842, and "Anatom. and Pathol. Observ.," p. 5—10.

‡ See Heidenhain in "Moleschott's Untersuchungen," band iv. 1858, p. 251; and Brücke in band viii. 1862, p. 495; and in "Denkschrift. d. k. Akad. d. Wiss. zu Wien," band vi. p. 105.

§ "Physiologie," 1863, p. 365.

consider it to be covered by a delicate septum perforated like a colander with extremely fine canals or pores. The small and attached extremities of these cells are believed to be prolonged into the interior of the villi, becoming continuous with the caudate processes of the corpuscles of the connective tissue (*d*) which constitutes the matrix, and which again open, as shown in Fig. 22, into the lacteal vessel (*c*), thus affording a direct means of entrance for the fatty matters into the absorbent system, and explaining the occasional introduction of solid particles into the circulating current.*

FIG. 22.



Diagrammatic representation of the Origin of the Lacteals in a Villus —*e* Central lacteal, *d*. Connective-tissue corpuscles with communicating branches; *c*. Ciliated columnar epithelial cells, the attached extremities of which are directly contiguous with the connective-tissue corpuscles.

108. In regard to the degree in which the function of Nutritive Absorption is performed by the Lacteals and by the Sanguiferous system respectively, considerable difference of opinion has prevailed. When the Absorbent vessels were first discovered, and their functional importance was perceived, it was imagined that the introduction of alimentary fluid into the vascular system took place by them alone. Such an idea, however, would be altogether inconsistent with the facts of Comparative Anatomy; † and it is completely negatived by the results of experiment. For that Absorption is effected to a very considerable amount by the agency of the Blood-vessels, is shown in the first place, by the readiness with which aqueous fluids and even alcohol are taken-up from the parietes of the Stomach, and are carried into the general circulation. Thus in a case of extroversion of the bladder, observed by Mr. Erichsen,‡ in which the urinary secretion could be collected immediately on its passing from the kidney, when a solution of ferrocyanide of potassium was taken into the stomach, this salt was detected in the urine in one instance within 1 minute, and in three other instances within 2½ minutes. In all these cases, however, the stomach may be presumed to have been

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* These epithelial cells were described by MM. Gruby and Delafond ("C. Rendus," 1843, 1195), as possessing cilia on their free margin; but Kolliker and Funke considered this appearance as illusory, and produced by the thick membrane closing the free extremity of the cell being perforated by very delicate pores or canals, whilst after death it split up in such a manner as to *resemble* a bundle of cilia (Kolliker, "Mikroskop. Anat.," 1860, p. 329). Balogh, agreeing with Kolliker as to the lines in question being canals, differed from him in believing them to be not pre-existent, but merely the indications of the passages made by the molecules of fat in penetrating the delicate tissue occluding the mouth of the cell ("Moleschott's Unters." band vii. 1861, p. 556.) Brettauer and Steinach, on whose observations the statements of Brucke, Heidenhain, and other later authors are founded (Brettauer and Steinach, "Sitzungsbericht d. k. Akad. d. Wissen. zu Wien," 1857, band xxiii. p. 303,) maintained that the apparent cilia were prolongations of the cell-contents, the cells themselves terminating with a smooth circular margin. They described the columnar arrangement as broadest and most distinct in fasting animals, whilst in cells filled with fat it diminishes to one-half or one-third of its former breadth, and the striæ disappear, so that only a bright narrow rim or border is left. Lastly, Wiegandt is stated in "Canstatt's Jahresbericht" for 1862, p. 32, to view the cilia as merely the optical expression of striæ or wrinkles.

† See "Princ. of Comp. Phys.," CHAP. IV.

‡ "Medical Gazette," vol. xxxvi. p. 363.

empty, and the vascular system in a state of aptitude for absorption; since the experiments were made either after a long fast, or at least four hours after a light meal. When, on the other hand, the salt was introduced into the stomach soon after the ingestion of alimentary substances, a much longer period elapsed before it could be detected in the urine; thus, when a substantial meal had been taken two hours previously, the interval was 12 minutes; when tea and bread-and-butter had been taken one hour previously, the interval was 14 minutes; a similar meal having been taken twenty-four minutes previously, the interval was 16 minutes; when only two minutes had passed since the conclusion of such a meal, the interval was 27 minutes; and when a solid meal had been concluded just before the introduction of the salt, the interval was 39 minutes.—These facts are of great importance, in showing the very marked influence which the state of the *stomach* exercises upon the absorption of matters introduced into it. Not less important, however, is the state of the *vascular system* in regard to turgescence or emptiness; for it was found by Magendie, that when he had injected a considerable quantity of water into the veins of a dog, poison was absorbed very slowly; whilst, if he relieved the distension by bleeding, there was speedy evidence of its entrance into the circulation.—The rapidity with which not only aqueous but alcoholic liquids introduced into the stomach may pass into the general circulation, has been shown by the experiments of Dr. Percy;* who found that when strong alcohol was injected into the stomach of dogs, the animals would sometimes fall insensible to the ground *immediately* upon the completion of the injection, their respiratory and cardiac movements ceasing within two minutes; and that on post-mortem examination in such cases, the stomach was nearly empty, whilst the blood was highly charged with alcohol; thus rendering it almost certain, that not merely the final destruction of nervous power, but the immediate loss of sensibility, was due to the action of alcoholized blood upon the nervous centres.—Finally, numerous experiments have been made by various physiologists, which have demonstrated that absorption of alimentary and other substances may take place from the walls of the Stomach; these substances having been prevented from passing into the intestine, by a ligature around the pylorus. Now, as the Absorbent system does not present that peculiar arrangement in the coats of the stomach, which it does in those of the intestinal tube, there can be little doubt that the introduction of such substances into the system must be effected chiefly, if not entirely, through the medium of its sanguiferous capillaries.

109. That the Blood-vessels of the Intestinal tube largely participate in the introduction of soluble alimentary matter into the system, has been clearly proved by various observations upon the constitution of the blood of the Mesenteric veins; these having shown, that after the digestion of albuminous and farinaceous or saccharine substances, albuminose, dextrin, grape-sugar, and lactic acid, are detectible in that fluid, whose usual composition is greatly altered by the presence of these substances, as well as by the augmented proportion of water which it contains. Moreover, it is asserted by Bruch,† that so large a

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* "Experimental Enquiry concerning the Presence of Alcohol in the Ventricles of the Brain," p. 61.

† Siebold and Kölliker's "Zeitschrift," April, 1853.

quantity of fat is absorbed into the blood-vessels, that the superficial capillary network sometimes presents an opalescent whiteness We may consider the Sanguiferous vessels, then, as affording the usual channel by which a large part of the nutritive materials are introduced into the system; but these are not allowed to pass into the general current of the circulation, until they have been subjected to an important *assimilating* process, which it appears to be one great office of the Liver to perform, whereby they are rendered more fit for the purposes they are destined to serve in the economy Of this we shall presently have to speak —But the absorbent power which the blood-vessels of the Alimentary canal possess, is not limited to alimentary substances, for it is through them almost exclusively, that soluble matters of every other description are received into the circulation This, which may now be considered a well-established fact, was first clearly shown by the carefully-conducted experiments of MM Tiedemann and Gmelin,* who mingled with the food of animals various substances, which, by their colour, odour, or chemical properties, might be easily detected in the fluids of the body after some time the animal was examined; and the result was, that unequivocal traces of such substances were not unfrequently detected in the venous blood and in the urine, whilst it was only in a very few instances that any indication of them could be discovered in the chyle The colouring matters employed were various vegetable substances, such as gamboge, madder, and rhubarb, the odorous substances were camphor, musk, asafœtida, &c ; while, in other cases, various saline bodies, such as chloride of barium, acetate of lead and of mercury, and some of the prussiates, which might easily be detected by chemical tests, were mixed with the food The colouring matters, for the most part, were carried out of the system, without being received either into the veins or the lacteals, the odorous substances were generally detected in the venous blood and in the urine, but not in the chyle, whilst of the saline substances, many were found in the blood and in the urine, and a very few only in the chyle † A similar conclusion might be drawn from the numerous instances, in which various substances introduced into the intestines have been detected in the blood, although the thoracic duct had been tied; but these results are less satisfactory, because, though there is probably no direct communication (as maintained by many) between the lacteals and the veins in the mesenteric glands, the partitions which separate their respective contents are evidently so thin, that transudation may readily take place through them

110 The process of absorption of the Blood-vessels is effected by the operation of forces of a purely physical character, the chief phenomena of which are embraced under the general term of Osmosis, and which may here be briefly noticed When two fluids, miscible with one another, are placed on the opposite sides of an animal membrane or other porous septum, currents are generally established in opposite directions, the activity of which is essentially dependent upon the nature of the septum and the

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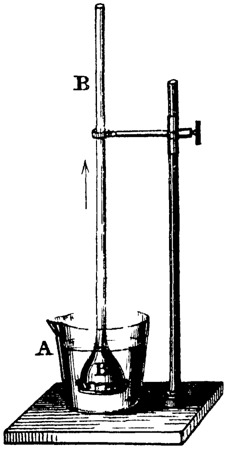
* "Versuche uber die Wege auf welchen Substanzen aus dem Magen und Darmkanal ins Blut gelangen," Heidelberg, 1820

† Colin, however, on examining the fluid of the Thoracic duct, readily found Iodide and Ferrocyanide of Potassium in dogs, sheep, and oxen, to which these salts had been administered eighteen minutes previously ("Bulletin de l'Académie," xxvii p 948)

affinity of the fluids for one another. The instrument by which these effects are best shown, is termed an Endosmometer, and consists (Fig. 23) of a tube B, whose wide extremity is partially filled with the fluid to be experimented-on, and is then immersed in a vessel of pure water A, the height of which is accurately kept at the same level as that to which the fluid rises or falls within the tube, in order to avoid the effect of unequal hydrostatic pressure. In the majority of experiments of this nature the membrane is capable of being wetted by the fluids on both sides, as when water and a solution of some salt are employed. It is then found that a strong current sets from the water to the saline solution, termed the endosmotic current, the energy of which is within certain limits proportional to the density of the solution,* whilst the amount of water entering will, of course, vary with the extent of surface presented by the membrane. On the other hand, the water without becomes impregnated with a portion of the salt from the establishment of a counter current, hitherto termed the exosmotic current, which will continue until the density of the fluids on the two sides of the membrane is equal. The experiments of Prof. Graham, Brucke, and others, however, render it probable that the passage of two *fluid* currents in opposite directions through the membrane is only apparent, and that the phenomena may in reality be explained by the admission of only a single current setting inwards from the pure water to the saline solution, the apparent exosmotic current being due to the particles of salt passing outwards by a process of solution in successive layers of the pure water contained in the pores of the membrane until the outer surface is reached, when they immediately *diffuse* into that liquid, giving rise to the appearance of a *fluid* current in the opposite direction. The great importance of the nature of the septum and of its capacity for imbibing or for being permeated by the liquids, is shown by the facility with which the experiment can be arranged in such a manner that a current shall only pass in one direction; for if the mouth of the instrument be closed with bladder, and alcohol be placed within it, on immersing it in water a current is immediately established from the water to the alcohol, the increased bulk of which can be ascertained by a scale attached to the upper part of B, but there will be no evidence of a counter current passing from the alcohol to the water. If, on the contrary, the mouth of the instrument be closed with a thin lamina of caoutchouc, a

FIG. 23.



An Endosmometer.

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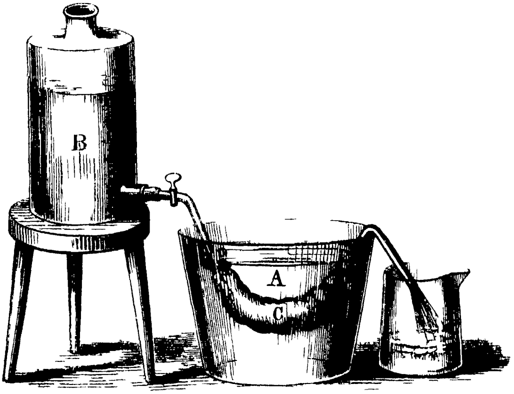
* It is considered by Liebig, that the purgative effects of concentrated saline solutions are to be accounted-for on this principle—the establishment of an osmotic current *from* instead of *towards* the circulating system. It is difficult, however, thus to account for all the phenomena of saline purgation; and the Author greatly doubts the validity of the explanation. Some experiments performed by Aubert are also strongly opposed to it, for he found that the injection of solutions of many of the neutral salts into the veins produced active purging: and here, of course, the explanation suggested by Liebig is inadmissible. (See "Zeitschrift für Nat. Med." 1832, t. ii., p. 225.)

current soon sets from the alcohol to the water, and therefore in the opposite direction. We may explain these phenomena by supposing that in the former instance the water possesses a superior attraction for the membrane, enters its pores by imbibition and capillary attraction, and driving the alcohol before it, reaches the inner surface of the membrane, whence it instantly diffuses into that fluid, partly in consequence of the mutual repulsive force of its own particles, and partly from their affinity to those of the alcohol. In the latter case the alcohol exerts the same influence by virtue of its superior affinity for the caoutchouc. Professor Graham, indeed, considers that the water movement in osmosis is simply an affair of hydration and dehydration of the substance of the membrane or other colloid septum, and that the diffusion of the saline solution placed within the osmometer has little or nothing to do with the osmotic result otherwise than as it affects the state of hydration of the septum.*

111. It is not absolutely necessary that the septum should be of a solid nature, since the same phenomena are observed, where, as in L'Hermite's experiment,† a layer of water constitutes the diaphragm, being made to separate a subjacent and heavier layer of chloroform from a superjacent and lighter layer of ether. The water is impermeable to chloroform, but permeable to ether, which therefore gradually penetrates through the water to the chloroform, and from its affinity for the latter, immediately diffuses into it, ultimately, in opposition to the force of gravity, entirely disappearing from the surface of the water. The importance of the miscibility of the fluids is clearly shown by the complete absence of currents which occurs when the fluids on the opposite sides of the septum have no affinity for one another, as in the case of oil and water, or of water and chloroform. But even when such affinity really exists, and when, as is usually the case in the animal body, there is more or less tendency in the fluids on the opposite sides of the septum to diffuse into one another, many

FIG. 24.



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* For a theory which is in close accordance with this, see Buchheimer (Beitrage), "Archiv f. Phys. Heilk.," 1853, t. xii.

† "Comptes Rendus," 1854, p. 1179.

circumstances may interfere to modify the force and direction of the osmotic currents besides those already noticed. Amongst these may be mentioned temperature,* pressure, electricity,† the specific heat of the fluids,‡ the process of evaporation, the previous impregnation of the membrane with acids§ or alkalies,‖ and lastly, one which is in constant operation in the living body, viz., the movement of one of the fluids, the effects of which may be clearly exhibited by means of an apparatus essentially the same as that constructed by Dr. Robinson, and shown in Fig. 24, where B is a vessel containing coloured fluid; C a piece of intestine attached to the stopcock of B on the one hand, and to a siphon on the other, and immersed in a vessel of water A. If the siphon be of smaller diameter than the portion of intestine C, as in the figure, the fluid will discharge itself with difficulty, the intestine will become tight, and an effusion of the coloured fluid into tho pure water contained in the vessel A will become apparent; but if the diameter of the siphon be greater than that of the intestine attached to it, the discharge of the fluid will take place easily, the membranous tube will become flaccid, and a rapid process of absorption of the water or of any saline solution in A will occur.¶ In a recent paper by Professor Graham,** of great interest in reference to the phenomena we are now discussing, that chemist shows that some substances, as the salts of the metals, generally pass through porous septa with facility; and these and all substances so diffusing themselves he proposes to call crystalloids; whilst others, as alumina, hydrated silicic acid, gum, dextrin, gelatin, albuminous substances, &c., pass with great difficulty, or not at all. These he denominates "colloids."†† The latter are characterized by possessing feeble chemical reactions; by diffusing very slowly in water; by having so weak an affinity for that liquid, that they are easily precipitated from their solution; by being unable to pass through (by means of diffusion) any colloidal septum; by their consequent insipid taste, since they probably never reach the sentient extremities of the gustatory nerves; and by their high equivalent numbers, unstable nature, and ready passage into decomposition. The crystalloids, on the other hand, present characters which are precisely the reverse.

112. There seems to be no reason for doubting that the absorption of the various nutritive and alimentary materials takes place according to the ordinary rules of Osmosis; for on the one hand is the aliment always more or less perfectly reduced to the liquid state, the density of which is generally less than that of the blood, in consequence of the very copious discharge of aqueous fluid into the alimentary canal during the operation of digestion; and on the other is the blood or lymph in rapid movement, possessing a high specific gravity, and at a temperature of 99° or 100° F.; whilst between them is the septum, of immense extent and great tenuity, formed by the mucous membrane and the walls of the blood or lymph

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* Eckhard, "Beiträge," 1858, p. 95.

† Brooke in "Golding Bird's Nat. Phil." 1860, p. 24.

‡ Béclard, "Physiologie," 1862, p. 176.

§ Harzer, "Archiv f. Phys. Heilk.," 1856, t. xv.

‖ Wistinghausen, "Dissert.," Dorpat, 1851.

¶ Robinson, "Contributions to Physiology," 1857, p. 98.

** "Trans. Royal Soc.," 1861, part i.

†† Redwood, 'Dialysis,' "Pharm Journ." Ap. 1862.

vessels: the tendency is, therefore, in accordance with the facts already stated, in favour of the passage of the aliment from the intestinal tract towards the circulating fluids.* As regards such substances as albumen, gum, and gelatine, which belong to the "colloid" class of substances, and therefore transude with extreme difficulty, it appears at first sight difficult to explain how they pass through the intestinal mucous membrane.† The experiments of Funke, however, show that the act of digestion essentially effects a conversion of the "colloid" group into the "crystalloid;" for that as soon as the albuminous substances introduced into the stomach have undergone the modification into peptones, they have acquired the power of traversing animal membranes with comparative facility. As the conditions for the absorption of these substances are alike present in the stomach and intestines, it is probable that this process takes place through the whole length of the alimentary tube, though chiefly in the intestine, as the presence of acids is unfavourable to its active performance; a view which receives support from the experiments of Busch ‡ upon the woman with a duodenal fistula, in whom it was found that a considerable portion of the saccharine, and about one-third of the albuminous compounds taken as food, were absorbed before reaching the intestine. Funke§ observed also that when solutions of peptone were introduced and secured by ligature in determinate lengths of the intestines of living rabbits, and permitted to remain for two, four, and six hours, the more concentrated the solution, the greater was the activity with which the absorption was accomplished in a given time; but that a remarkable difference occurred from what might have been anticipated, where a definite quantity of the solution of peptone was presented to double the extent of surface, very little more being then absorbed, or at least nothing like double the amount in the same time. He further found that the amount absorbed in the living animal by no means stands in direct relation to the duration of the experiment, the process taking place with far more energy during the first hour than subsequently; and the same facts were also observed in experiments upon the absorption of sugar made by Becker.‖

113. The difficulty which formerly existed in regard to the absorption

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* Some exceptional instances have not yet received full explanation. Thus, the poison of the serpent, and the American poison, Woorara, have long been known to be harmless when swallowed; and this has recently been shown by Bernard to be due, not as was formerly supposed to the decomposition of the poison by the Gastric Juice, but to the circumstance that it will not pass through the mucous membrane of the stomach or intestine unless introduced in very large quantities. In like manner M. Renault has made the curious observation that the flesh of animals which have died of malignant pustule, the virus of glanders, and some other animal poisons, can be introduced into the stomach of Dogs, Pigs, and Fowls, without propagating the disease, whilst they are readily absorbed by the mucous membrane of the Goat, Sheep, and Horse. ("Rec. de Méd. Vétérin.," 1851, xxviii. p. 873.)

† Mialhe ("Chimie appliquée à la Physiologie," 1856,) broke the shell from the end of an egg, leaving the membrane intact, and immersed it in water. After 5 hours it had increased in weight upwards of 30 grains, and the membrane was tight and prominent. The water in which the egg had been immersed became alkaline from the exosmose of the salts, but no albumen had escaped. So Graham and Eckhard ("Beiträge," band iii. p. 51 and 85, 1862,) state that in analogous experiments with solutions of gum no exosmosis of that substance occurred.

‡ "Archiv f. Path. An. und Physiologie," 1858, band xiv. p. 140.

§ "Physiologie," 4th Edit., 1863, p. 357.

‖ "Zeitschrift f. wiss. Zoologie," 1854, t. v., p. 137 *et seq.*

of fatty bodies into the *absorbent vessels*, since these traverse moist animal membranes with great difficulty, is in some measure set aside by the observations of MM. Heidenhain and Brücke already detailed, though there are still some points which have not received explanation.* Their entrance into the *blood-vessels* may be aided, as Béclard† supposes, by the direct pressure of the muscular coats of the intestines; for, though great force is requisite to drive oil through the entire thickness of the walls of the small intestine, a much slighter one will suffice to impel it through the delicate structure of the mucous membrane alone, especially if the oil be finely divided or emulsionized: the yolk of egg, for instance, mingled with two or three times its weight of water, traversing such a membrane at a temp. of 100° F., and under a low pressure with great ease; though in other experiments made by M. Morin ‡ much difficulty was experienced with milk, on account of the much larger size of the molecules of oil contained in that fluid. It is certain, moreover, that the presence of a weak solution of soda or potash in the pores of the membrane, which effects a saponification of the oil, materially facilitates its passage; § and Wistinghausen and Hoffmann ‖ have observed that the force requisite to drive oil through an animal membrane is materially diminished by first impregnating the latter with bile: an important observation in reference to the phenomena of the absorption of these substances by the blood-vessels, since it renders it probable that, as in the case of the albuminous compounds, it is in the small intestine chiefly, the surface of which is rendered alkaline by its own secretion and by the fluids discharged by the Liver and Pancreas, that the absorption of fat is accomplished.¶

114. It is a very remarkable fact, which has recently been fully substantiated, that not merely soluble matters, but insoluble substances in a state of minute division, may find their way from the alimentary canal into the current of the circulation. Thus it was found by Oesterlen ** that particles of finely-divided charcoal, introduced into the alimentary canal, could be distinguished in the blood of the mesenteric veins; and similar results have been obtained by Eberhard, and by Mensonides and Donders, not only with charcoal, but also with sulphur and even with starch, the latter substance being at once detectible in the blood by the iodine-test. There can be little doubt that such substances enter the lacteal system, through the epithelial cells of the villi; as the presence of psorosperms in the interior of these has been distinctly perceived by Klebs.††

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* For a very full and interesting critique upon the whole question of the absorption of Fats, see Funke, "Physiologie," 1863, 4th Edit., p. 359—372.

† "Physiologie," 1862, p. 181. ‡ "Mémoires de la Société de Genève," 1854.

§ Matteucci, "Lectures on the Phys. Phenom. of Living Beings," Pereira's Edit., p. 111.

‖ "Dissert. inaugur." Dorpat, 1851.

¶ For the best and most recent account of the various phenomena of imbibition, capillarity, osmosis, and diffusion of liquids, see Milne Edwards, "Leçons sur la Physiologie," vol. v., 1859, in which the literature of the subject is given in a singularly perfect manner. See also Prof. Graham's Memoirs in the "Phil. Trans." for 1850, 1854, 1857, &c.

** "Heller's Archiv," 1847.

†† For further information on this point the reader is referred to "Moleschott's Untersuchungen," band ii. p. 119; and "Wien. Med. Wochenschrift," 1854, p. 817. "Hollander Quæstiones de Corp. solid. e tract. intest.," &c., Dorpat, 1856. Teichmann, "Das Saugader System," 1861, p. 106. Funke, "Lehrbüch," 1863, 4th edit., p. 362 *et seq.*; and Klebs, in "Arch. f. Path. Anat.," band xvi., p. 188.

2.—*Absorption from the Body in general.*

115.—The Mucous Membrane of the alimentary canal is by no means the only channel through which nutritive or other substances may be introduced into the circulating apparatus from external sources. The *Lymphatic* system is present in all animals which have a *lacteal* system; and the two, as already pointed-out, evidently constitute one set of vessels. The Lymphatics, however, instead of commencing on the intestinal walls, are distributed through most of the vascular tissues of the body, and especially in the Skin; but their number bears no proportion whatever to the vascularity of the several tissues, or to the amount of interstitial change which these undergo; and it would rather seem to be related to the amount of Connective tissue interposed between the other constituents of the fabric (§ 121). Thus we find the Nervous centres entirely destitute of them, unless indeed they are represented by the lacunar spaces filled with nuclei, which have been described by Robin* as surrounding the capillaries; and they are very scanty in the substance of Muscles. After passing, like the lacteals, through a series of glandular bodies (the precise nature of which will be presently considered, § 121), they empty their contents into the same receptacle with the lacteals; and the mingled products of both pass into the Sanguiferous system.—We find in the Skin, also, a most copious distribution of capillary blood-vessels, the arrangement of which is by no means unlike that of the blood-vessels of the alimentary canal; and its surface is further extended by the elevations that form the sensory papillæ, which are in many points comparable to the intestinal villi, although their special function is so different.

116. In the lowest tribes of animals, and in the earliest condition of the higher, it would seem as if Absorption by the *external surface* is almost equally important to the maintenance of life, with that which takes place through the internal reflexion of it forming the walls of the Digestive cavity. In the adult condition of most of the higher animals, however, the special function of the intestinal tract is so much exalted as usually to supersede the necessity of any other supply; and the function of the cutaneous and pulmonary surfaces may be considered as rather that of exhalation, than of absorption.† But there are peculiar conditions of the system, in which the imbibition of fluid through these surfaces is performed with great activity, supplying what would otherwise be a most important deficiency. It may take place either through the direct application of fluid to the surface, or even through the medium of the atmosphere, in which a greater or less proportion of watery vapour is usually dissolved. This absorption occurs most vigorously, when the system has been drained of its fluid, either by an excess of the excretions, or by a diminution of the regular supply.

* Brown-Séquard, "Journal de la Physiol.," vol. ii. 1859, p. 537.

† We have a remarkable exception to this general statement, however, in the case of Frogs and other Batrachia, which are characterized by the softness of their skins and the thinness of their epidermic covering; for cutaneous absorption seems in them to be no less active than their cutaneous exhalation and respiration are well known to be. Thus Frogs, which habitually live in a moist atmosphere, seldom or never drink; yet when they have lost fluid by exposure to hot dry air, they will regain their weight by being left for a time upon moist sand; and the bladder, which serves as a reservoir of water for cutaneous exhalation, though previously emptied, will be refilled.

117. It may be desirable to adduce some individual cases, which will set this function in a striking point of view; and those may be first noticed, in which the Absorption took place through the contact of *liquids* with the skin. It is well known that shipwrecked sailors and others who are suffering from thirst, owing to the want of fresh water, find it greatly alleviated, or altogether relieved, by dipping their clothes into the sea and putting them on whilst still wet, or by frequently immersing their own bodies.*—In a case related by Dr. Currie, of a patient labouring under dysphagia in its most advanced stage (the introduction of any nutriment, whether solid or fluid, into the stomach, having become perfectly impracticable), an attempt was made to prolong his existence by the exhibition of nutritive enemata, and by immersion of the body, night and morning, in a bath of milk and water. During the continuance of this plan, his weight, which had previously been rapidly diminishing, remained stationary, although the quantity of the excretions was increased. How much of the absorption, which must have been effected to replace the amount of excreted fluid, is to be attributed to the baths, and how much to the enemata, it is not easy to say; but it is important to remark that "the thirst, which was troublesome during the first days of the patient's abstinence, was abated, and, as he declared, removed, by the tepid bath, in which he had the most grateful sensations." "It cannot be doubted," Dr. Currie observes, "that the discharge by stool and perspiration exceeded the weight of the clysters;" and the loss by the urinary excretion, which increased from 24 oz. to 36 oz. under this system, is only to be accounted-for by the cutaneous absorption.†—Dr. S. Smith mentions that a man, who had lost nearly 3 lbs. by perspiration, during an hour and a quarter's labour in a very hot atmosphere, regained 8 oz. by immersion in a warm bath at 95°, for half an hour.‡—The experiments of Dr. Madden§ on his own person show that a positive increase usually takes place in the weight of the body, during immersion in the warm bath, even though there is at the same time a continual loss of weight by pulmonary exhalation, and by transudation from the skin.‖ This increase was, in some instances, as much as 5 drachms in half an hour; whilst the loss of weight during the previous half-hour had been 6½ drachms: so that, if the same rate of loss were continued in the bath, the real gain by absorption must have been nearly an ounce and a half. Why this gain was much less than in the cases just alluded-to, is at once accounted-for by the fact that there was no deficiency, in the latter case, of the fluids naturally present in the body.

118. There are certain phenomena, which, if accurately recorded, cannot be accounted-for in any other way, than by admitting that, under particular circumstances, a considerable amount of water may be absorbed from the *vapour* of the atmosphere. The following are among the most

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[*] See a collection of such cases in Dr. Madden's "Experimental Enquiry into the Physiology of Cutaneous Absorption," p. 47.

[†] "Medical Reports," vol. i. pp. 308—326.

[‡] "Philosophy of Health," vol. ii. p. 396.

[§] Op. cit., pp. 59—63.

[‖] That part of the function of Cutaneous Transpiration, which consists in simple Exhalation, is of course completely checked by such immersion; but that which is the result of an actual Secreting process in the cutaneous glandulæ (CHAP. XII. Sect. 4) is increased by heat, even though this be accompanied with moisture.

satisfactory and circumstantial observations, that have been adduced in support of this position. Lining observed that his body on one occasion increased in weight, during two hours, to the amount of 8½ oz.; allowance being made for the amount of fluid ingested during that time, and for the quantity passed-off by the urine and by cutaneous transpiration.* Dr. Jurin affirms that he ascertained an increase of 18 oz. to have taken place during a night passed in a cool room, after a day's exercise and abstinence.† It is stated by Dr. Watson,‡ that a lad at Newmarket, having been almost starved, in order that he might be reduced to a proper weight for riding a match, was weighed at 9 A.M., and again at 10 A.M.; and he was found to have gained nearly 30 oz. in weight in the course of this hour, though he had only drunk half a glass of wine in the interim. A parallel instance was related to the Author by the late Sir G. Hill, then Governor of St. Vincent: a jockey had been for some time in training for a race, in which that gentleman was much interested, and had been reduced to the proper weight; on the morning of the trial, being much oppressed with thirst, he took one cup of tea; and shortly afterwards his weight was found to have increased 6 lbs., so that he was incapacitated for riding.—Nearly the whole of the increase in the former case, and at least three-fourths of it in the latter, must be attributed to absorption from the vapour of the atmosphere; probably, however, rather through the lungs than through the skin. If the possibility of such absorption be admitted, we are probably to attribute to it the chief part of the excess of watery fluid which cannot be otherwise accounted for, in the following instances.—Dr. Hill§ relates the case of a diabetic patient, who for five weeks passed 24 lbs. of urine every twenty-four hours; his ingesta during the same period amounted to 22 lbs. At the commencement of the disease, he weighed 145 lbs.; and when he died, 27 lbs. of loss had been sustained. The daily excess of the excretions over the fluid ingesta could not have been less than 4 lbs.; making 140 lbs. for the thirty-five days during which the complaint lasted. If from this we deduct the amount of diminution which the weight of the body sustained during the time, we shall still have 113 lbs. to be accounted for, which can only have entered the body from the atmosphere.—A case of ovarian dropsy has been recorded by Mr. Ford,‖ in which it was observed that the patient, during eighteen days, drank 692 oz. or 43 pints of fluid, and that she discharged by urine and paracentesis 1298 oz. or 91 pints, which leaves a balance of 606 oz. or 38 pints, to be similarly accounted for.¶

119. The capacity of the Skin to absorb saline or other substances in solution, though formerly generally admitted, has lately been called in question by various observers. In experiments performed by Murray Thomson,** with which those of Parisot†† and Kletzinsky are in accordance,

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[*] "Philosophical Transactions," 1743, p. 496.

[†] Klapp, "Inaug. Dissert.," p. 30, cited by Dr. Madden.

[‡] "Chemical Essays," vol. iii. p. 100.

[§] "Trans. of Med.-Chirurg. Soc. of Edinb.," vol. ii.

[‖] "Medical Communications," vol. ii. p. 130.

[¶] In this case, however, as in others of a similar kind, something is to be allowed for the quantity of water contained in the solid food ingested; but this may be fairly considered not to exceed the quantity lost by pulmonary and cutaneous exhalation, and discharged in the fæcal evacuations.

[**] "Edin. Med. Jour.," 1862, p. 1017. [††] "Archiv. Gén. de Méd.," 1863, p. 376.

it was found that no trace of iodine could be detected in the morning urine, when a bath, containing half an ounce of iodide of potassium dissolved in 80 gallons of water had been taken the previous night after six hours' abstinence from all food. Homolle, who has paid much attention to this subject,* whilst admitting that pure water is certainly absorbed, and that saline solutions and some organic mixtures are sometimes decomposed by the skin, apparently by that tissue exerting an elective affinity for one of the constituents, to the exclusion of the others, yet states that in many instances in which he remained for an hour or more at a time in baths containing 3 oz. of cyanide or iodide of potassium, nitrate of potash, or chloride of ammonium, he was unable to discover any trace of those salts in the urine, nor did he perceive any physiological effect from the employment of baths in which 1 lb. of belladonna or of digitalis leaves had previously been infused. M. Willemin† and M. Delore,‡ on the other hand, maintain that the healthy skin is capable of absorbing not only water, but small portions of all substances soluble in water; the process of absorption varying under different circumstances, but being favoured by a delicate skin, and by exhaustion, though it does not take place when the skin is actively perspiring from exercise. The occasional serious effects upon the urinary organs of the application of a blister, the tinging of the urine with madder, rhubarb, and turmeric after bathing in infusions of those substances,§ and lastly, the remarkable experiment of Schreger, who found on immersing the hind leg of a puppy for 24 hours in tepid milk, after having previously applied a bandage, that the lymphatics were full of milk, though the veins contained none, are all favourable to the latter opinion. The process of absorption of saline substances by the skin is, however, so irregular and imperfect, that the iatroleptic plan of treatment will probably never be extensively employed. When absorption does take place, we should expect that the absorbed substances would be more readily discoverable in the absorbents than in the veins; for their imbibition takes place entirely according to the physical laws already mentioned, in conformity with which they pass most readily into the vessels which present the thinnest walls and the largest surface.

120. Our inferences with regard to the ordinary functions of the Lymphatic system, however, must be rather drawn from the nature of the fluid which it contains, and from the uses subsequently made of it, than from such experiments as the preceding. We shall presently see, that there is a close correspondence in composition between the Chyle of the Lacteals, and the Lymph of the Lymphatics; the chief difference being the presence of a considerable quantity of fatty matter in the former, and of a larger proportion of the assimilable substances (albumen and fibrin) which are equally characteristic of both (§ 123). This evident conformity in the nature of the fluid which these two sets of vessels transmit, joined to the fact that the fluid Lymph, like the Chyle, is conveyed into the general current of the circulation, just before the blood is again transmitted to the system at large, almost inevitably leads to the inference,

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* 'De l'Absorption par la Tégument externe,' "L'Union Médicale," 1853, p. 462 *et seq.*

† "Archiv. Gén. de Méd.," 1863, pp. 5—105—325. ‡ Ibid., p. 376.

§ "Medical Communications," vol. ii. p. 130.

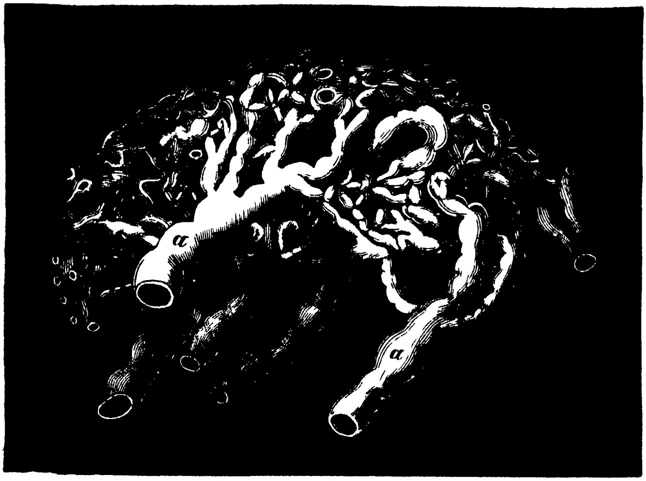
that the lymph is, like the chyle, a *nutritious* fluid, and is not of an excrementitious character, as maintained by Hunter and his followers. On the other hand, the close resemblance between the contents of the Lymphatics and diluted Liquor Sanguinis seems to indicate that the former are chiefly derived from the fluid portion of the blood, which has transuded through the walls of the capillary vessels, and has permeated the tissues, giving up to them the materials required for their nutrition. And we shall presently see reason to believe that this transudation answers the additional purpose of subjecting the crude materials, which may have been taken up direct into the blood-vessels, to an elaborating or preparatory agency, such as it seems to be the especial object of the Lacteal system to exert upon the nutritive substances which *it* serves to introduce into the circulation.—But it seems not impossible, that there may be another source for the contents of the Lymphatics. We have already had to allude, on several occasions, to the disintegration which is continually taking-place within the living body; whether as a result of the limited duration of the life of its component parts, or as a consequence of the decomposing action of Oxygen. Now the *death* of the tissues by no means involves their immediate and complete destruction; and there seems no more reason why an animal should not derive support from its own dead parts, than from the dead body of another individual. Whilst, therefore, the matter which has undergone too complete a disintegration to be again employed as nutrient material, is carried-off by the excreting processes, that portion which is capable of being again assimilated, may be taken up by the Lymphatic system. If this be the case, we may say with Dr. Prout, that "a sort of digestion is carried-on in all parts of the body."—It may be stated, then, as a general proposition, that the function of the Absorbent System is to take-up, and to convey back into the circulating apparatus in a state of higher elaboration, such substances as are capable of appropriation to the *nutritive* process; whether these substances be directly furnished by the external world, or be derived from the disintegration of the organism itself. We have seen that, in the Lacteals, the selecting power is such, that these vessels are not disposed to convey into the system any substances but such as are destined for this purpose; and that extraneous matters are absorbed in preference by the mesenteric Blood-vessels. The case is different, however, with regard to the Lymphatics; for there is reason to believe that they are more disposed than the venous capillaries to the absorption of other soluble matters, especially when these are brought into relation with the skin, through which the Lymphatic vessels are very profusely distributed.

3.—*Of the Elaboration of the Nutrient Materials.—Sanguification.*

121. The alimentary substances, taken-up by the Blood-vessels and Absorbents, seem very far from being capable of immediate application to the nutrition of the body; for we find that they are not conveyed by any means directly into the circulating current, but that those which enter the Gastro-intestinal veins are submitted to the operation of the Liver, whilst those which are received into the Lacteals are subjected to a kind of glandular action within their own system; the newly-absorbed

materials in both cases undergoing considerable changes, which tend to assimilate them to the components of the Blood.—The Lymphatic System consists of an extensive network of vessels very generally distributed throughout the body, but present in remarkable abundance beneath the Skin and Mucous membranes. The question of their origin cannot, as yet, be regarded as satisfactorily determined: Teichmann[*] believing that they commence in the form of stellate cells (which appear to be identical with the connective-tissue corpuscles), whose prolongations everywhere communicate, forming an irregular kind of network; whilst in a recent and carefully drawn up Report by C. Ludwig,[†] of a series of researches undertaken by himself and his friends, Herren Noll, Krause, Schwanda, and Tomsa, it is maintained that the real origin of the Lymphatics throughout the body is in the interspaces of the connective tissue, the lacunar spaces, splits, and fissures existing between the fibres of which, communicate with vessels which gradually assume a more definite form, and are then supplied with valves. No communication ever takes place between the Lymphatic and the Blood-vessels, except at the point where the great trunks empty themselves into the junction of the subclavian and jugular veins. It is a peculiarity of the Lymphatics that they do not present the same smooth and regular contour, nor the same definite mode of branching, that is met with in the Blood-vessels; on the contrary, they run irregularly, and the walls of the vessels often present dilatations or reservoirs in their course, whilst the larger vessels formed by the reunion of several smaller ones often again subdivide and reunite. The smaller vessels or Capillary Lymphatics are usually larger than the corresponding

FIG. 25.



A section of a simple Rete Mirabile, viewed from the surface.—*a*, *a*, afferent vessels; *b*, *b*, efferent vessels, only partially visible, from the popliteal space. (Man.)

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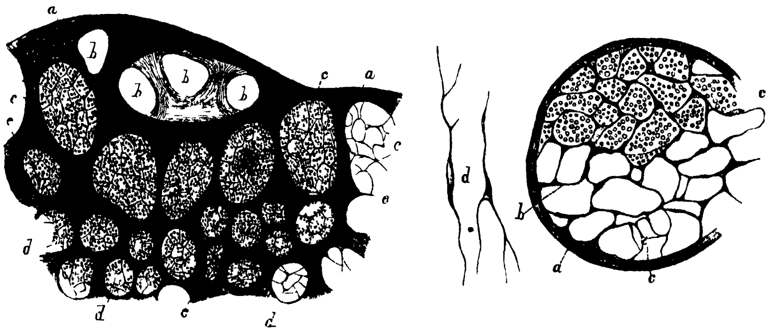
[*] Teichmann, "Das Saugader System."

[†] In the "Medizinischer Jahrbücher" of A. Duchek and A. Schauenstein, 1863, heft iv. p. 35—72, Wien.

capillary blood-vessels, and are lined by a tesselated epithelium (Recklinghausen). At certain parts of the body, as the bend of the knee and elbow, and in the neck, the larger stems suddenly break up into a dense interlacing network of capillary vessels, most distinct in young subjects, forming a *rete mirabile*, as is shown in Fig. 25. This is surrounded by condensed connective tissue, and is penetrated by blood-vessels; and is, so to speak, the first step towards the formation of a lymphatic gland. From this simple structure we can readily ascend through a series of gland-like organs, gradually increasing in complexity, composed of several of these little retia, arranged either continuously or in groups, until at length, by steps of easy transition, we arrive at the complex structure of the true lymphatic glands. These have been most laboriously investigated and excellently described by His,* Recklinghausen,† and especially by Teichmann‡ and Frey.§ From their investigations we learn that each gland is invested by a vascular sheath or capsule of condensed connective tissue, which is continuous with the coats of the afferent and efferent vessels, sending inwards a number of thin lamellæ, so disposed and connected together as to constitute a tolerably regular alveolated framework pervading the gland, excepting usually near the centre. The septa thus formed contain in Man and many other animals, but especially in the Ruminants, numerous muscular fibre-cells.‖ The alveoli are most distinct near the surface of the gland: towards the centre, in consequence of the breaking up and irregular disposition of the septa, they are not very apparent. The centre of the gland is occupied by the medullary substance, varying considerably in amount in different instances, but always most abundant in childhood, and in the more deeply seated glands. Its relation to the alveoli

A FIG. 26. B



Section of *Lymphatic Gland*, showing *a, a*, the fibrous tissue which forms its exterior; *b, b*, superficial vasa inferentia; *c, c*, larger alveoli, near the surface; *d, d*, smaller alveoli of the interior; *e, e*, fibrous walls of the alveoli.

Section of one of the alveoli of a Lymphatic Gland; *a, a*, its fibrous envelope, *b, b*, prolongations from this, intersecting and subdividing the general cavity; *c, c*, nuclei of the fibre-cells; *d*, separate fibre-cells.

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* "Untersuchungen über den Bau der Peyerschen Drüsen," Leipzig, 1862.

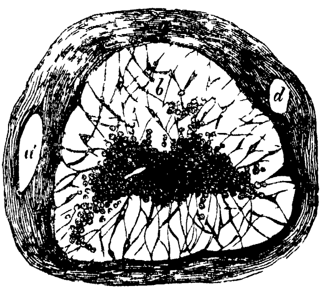
† "Die Lymphgefässe," Berlin, 1862. ‡ "Das Saugader System," 1861.

§ "Untersuchungen über die Lymph-drüsen des Menschen," Leipzig, 1861.

‖ Brücke, Recklinghausen.

may best be understood by conceiving it to be a plastic substance, accumulated in mass at the centre, and sending out on all sides prolongations of the most irregular form and shape, which do nearly, but *not completely*, fill the alveoli, spaces being consequently left between the septa which form the alveoli, and the processes of medullary substance partially filling them. These are termed by Frey the investing spaces of the follicle, represented by *b* in Fig. 27. They are traversed by irregular fibres, which resemble the Chordæ Willisii, found in the superior longitudinal sinus. According to Recklinghausen, they are lined by epithelium-cells of a rounded polygonal form, and certainly contain numerous lymph-corpuscles. They are directly continuous with the afferent and efferent vessels, and may be filled with injection propelled from either of those sets of tubes; though, of course, on account of the valves, more readily through the former than the latter. The course which the lymph takes in traversing these somewhat lacunar spaces around and between the alveoli, is termed by Frey the superficial lymph-path; but his observations have further shown that the medullary substance may be regarded as composed of a convoluted mass of branched and reticulated lymphatic canals, resembling Fig. 25, which, by their union and coalescence, form irregular dilatations and cavernous spaces, into the interior of each of which one or more blood-vessels penetrate; a space being left between the outer surface of the wall of the blood-vessel, and the inner surface of the very delicate transparent structure forming the wall of the lymphatic vessel. In this space great numbers of lymph- and after food, of chyle-corpuscles, are visible. These lymph-tubes communicate at numerous points with the above-mentioned lacunar spaces, which form the superficial lymph-path; but injections penetrate into them with some difficulty, a greater pressure, acting for a longer time, being required to fill them. In the interspaces of this system of anastomosing or branched canals, constituting the medullary portion of the gland, is interposed a quantity of connective tissue, the relations of which are very remarkable. It consists of a series of fine tubes, which open not only into the lymphatic tubes of the medullary substance, but also into the alveolar investing spaces, by numerous minute apertures, whilst they everywhere intercommunicate amongst themselves, forming irregular dilatations, and sometimes cavernous spaces, in which lymph-corpuscles are accumulated, and through which, as through a diverticulum, the lymph must slowly percolate, constituting the deep or internal lymph-path of Frey. A similar connective-tissue network is found in the alveoli, but it is much less developed, and its relations are much less distinct than in the medullary portion of the gland. It thus appears, that the lymph or chyle entering one of the

FIG. 27.

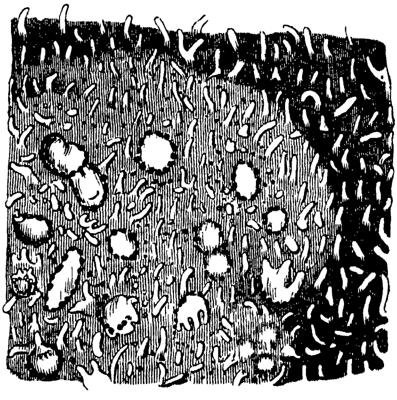


Simple Lymphatic Gland. *a*, The capsule with sections of lymphatics, *d*, *d*, coursing through it; *b*, Lacunar and intercommunicating passages, permeated by the lymph, and forming the superficial lymph-path of Frey. *c*, Nucleus or medullary portion of the gland, in the centre of which the section of a blood-vessel may be seen. In the path pursued by the lymph, star-shaped cells or cell-like enlargements usually destitute of nuclei may be seen, which constitute the deep or secondary lymph-path of Frey.

mesenteric glands passes, under ordinary circumstances, from the afferent to the efferent vessels, through the superficial lymph-path, that is, chiefly through the investing follicular spaces around and between the alveoli; though partly also through the lymph-tubes forming the medullary portion of the gland, where it comes into intimate relation with the blood-vessels, and takes up a certain proportion of lymph-corpuscles. When, however, the activity of the gland is at its height, as regards both the circulation of the blood and that of the lymph, as after food, the pressure of the increased quantity of the latter fluid effects the dilatation of the minute pores by which the plexus of the connective-tissue corpuscles and their prolongations communicate with the medullary tubes and alveolar investing spaces, thus permitting a slow percolation of the newly-absorbed fluid through channels in which lymph-corpuscles are abundantly contained, and effecting the first steps in its assimilation to that fluid, into which it is subsequently poured, and of which it is obvious that it constitutes the pabulum.

122. The whole of the *Lacteal* and *Lymphatic* system may thus be looked-upon as constituting one great *Assimilating Gland*, dispersed through the body at large; for it does not differ in any essential particular from what the Kidney or the Testis would be, if it were simply unravelled, and its convoluted tubuli spread through the entire system, yet still all discharging their secreted products by a common outlet. In the cold-blooded Vertebrata, the Absorbent system *appears* to attain a relatively greater development than it does in the higher classes; but the difference really lies in the greater extension, in the former, of those glandular elements which are more concentrated in the latter (See PRINC. OF COMP. PHYS., §§ 184—187).—Scattered through the whole length of the intestinal mucous membrane, from the Stomach to the Rectum, are certain peculiar bodies, which are known as *Peyer's Glands*. These may be either 'solitary' or 'agminated;' the former being very generally distributed throughout the intestinal canal, whilst the latter are restricted to the small intestine, being most abundant at the lower part of the ileum. In whatever portion of the canal they may occur, they are always limited in situation to that part of its periphery which is opposite to the mesentery. Each 'Peyerian gland,' in a healthy nucous membrane, presents appearance of a circular, .te, slightly-raised spot, about a line in diameter, over which the memne is usually less beset with villi, and is very often entirely destitute hem; and it is surrounded by a ring of openings, which are the orifices

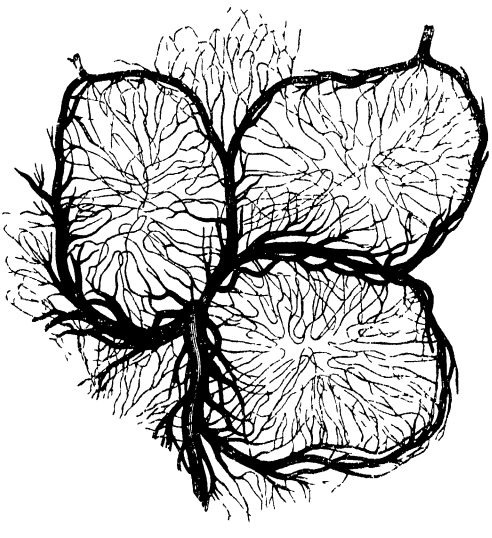
FIG. 28.



Portion of the mucous surface of the end of the Human Ileum, moderately magnified, showing the *Peyerian Glands*, the orifices of the follicles, and the villi.

of a set of cæcal follicles disposed in a zone around it (Fig. 28). The 'Peyerian patches' (Figs. 20, 21 and 28) present aggregations of these spots, varying in number from two upwards, but every one of their individual components having precisely the same structure as the solitary gland. This appears, from the researches of Brücke, Kölliker, and others, to be a sort of capsule, whose walls are composed of indistinctly-fibrillated connective tissue with interspersed nuclei, and whose contents are thus but imperfectly differentiated from the tissues in which the gland is imbedded. These contents are made-up of a granular 'plasma,' containing fatty and albuminous molecules of various sizes, with nuclear particles, and a few cells; altogether presenting an appearance of being the seat of rapid changes of progressive metamorphosis. Each capsule is surrounded by a close vascular network; and according to the observations of Frey, which have been confirmed by Kölliker,* capillary vessels pass freely into the midst of its contents, and then return by loops, as shown in Fig. 29. According to the researches of Teichmann,† these

Fig. 29.



Horizontal Section through the middle plane of three *Peyerian Glands* in the *Rabbit*, showing the distribution of the blood-vessels in the interior.

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* "Mikroskopische Anatomie," band ii. § 171.

† Teichmann's investigations were chiefly made by means of injections; but His, who examined thin sections of the intestinal mucous membrane after merely washing them with water and a camel-hair brush ("Untersuch. über den Bau du Peyerischen Drüsen," Leipzig, 1862, p. 7), maintains the elaborate system of vessels described by Teichmann to be only splits or fissures in the membrane between the follicles, traversed by fibrous cords and bands, and containing blood-vessels. At the same time he agrees with the view that they serve as channels for the conduction of the chyle. He considers that the proper substance of the parietes of the follicles is continuous with that of the villi and subjacent portion of the mucous membrane; both consisting of a matrix of areolar tissue with nu-

bodies are never penetrated by any lacteal vessels, though their presence in the mucous membrane occasions considerable disturbance in the usual arrangement of the lacteal system. The figures on page 111 show clearly the relations which they hold to the surrounding vessels, together with the general structure of the small (Fig. 20) and large intestine (Fig. 21). In their course through the mesentery, the Lacteals pass into the bodies known as the *Mesenteric Glands*, which stand in the same relation to them that the *Absorbent Glands* of the body generally do to the Lymphatics.

123. *Composition and properties of the Chyle and Lymph.*—The chief chemical difference between these fluids consists in the much smaller proportion of solid matter in the Lymph, and in the almost entire absence of fat, which is an important constituent of the Chyle. Lymph is, in general, a colourless, transparent fluid, sometimes yellowish, and sometimes turbid or opalescent, having a faint odour, salt taste, and alkaline reaction. Its chemical characters, according to Ludwig, vary considerably at different periods, and even in different parts of the system at the same time; so that of the fluids taken from the two sides of the neck, it will sometimes happen that one will coagulate spontaneously, whilst the other remains fluid. A considerable though variable number of corpuscles and minute oil-globules are generally present; the former, like those of the Chyle, resembling the white corpuscles of the blood, and the latter being especially abundant after food. The following table shows the results of some of the most accurate analyses that have been made upon human Lymph:*—

In 1000 Parts.	Gubler and Quevenne.		Marchand and Colberg.	Scherer.	Nasse.
	I.	II.	III.	IV.	V.
Water	939·87	934·77	969·26	957·60	910·60
Solid residue . . .	60·13	65·23	30·74	42·40	60·50
Fibrin	0·56	0·63	5·20	0·37	1·65
Albumen	42·75	42 80	4·34	34·72	—
Fat	3·82	9·20	2·64	—	—
Extractives . . .	5·70	4·40	3·12	—	—
Salts	7·30	8·20	15·44	7·31	—

The Lymph examined in the analyses numbered I. and II. was obtained from the thigh of a healthy woman 39 years of age; that in No. III. from a wound on the dorsum of the foot; that in No. IV. from a saccular dilatation of a Lymph-vessel of the spermatic cord; and that

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cleated cells imbedded in it, and of capillaries, the latter being sparingly distributed to the follicles, causing them to appear like clear spaces in fine sections. He applies the term adenoid tissue to the matrix of the follicles, and to the surrounding tissue of the intestinal mucous membrane. The Lieberkuhnian Glands are imbedded in this adenoid substance, and immediately external to them is the muscular layer (Brucke) of the mucous membrane. He believes, lastly, that the cells imbedded in the adenoid substance become blood-corpuscles.

* v. Gorup-Besanez, "Physiologische Chemie," 1862, p. 358.

in No. v. from a lymphatic fistula. Leucine, Sugar, and Urea have been found in the Lymph; the latter in the very perceptible proportion of 0·1 to 0·2 parts per 1000 (Wurz).

124. In fasting animals, the composition of the *Chyle* appears to resemble very closely that of the Lymph, but during digestion its qualities sensibly alter. The following analyses will enable a comparison to be made between the Chyle and Lymph:—

In 1000 Parts.	Man.	Cow.	Horse, Thoracic Duct.	Ass, Thoracic Duct.	Dog.	Cat.
	Owen Rees.	Lassaigne.	Simon.	Owen Rees.	Schmidt.	Nasse.
Water	904·8	964·40	928·23	902·37	916·65	905·7
Solid residue . . .	95·2	35·60	71·57	97·63	83·35	94·3
Fibrin	traces	0·95	0·72	3·70	2·12	1·30
Albumen	70·80	28·0	49·89	35·16	35·75	48·90
Fat	9·20	0·40	4·89	36·01	33·02	32·70
Extractives	10·8	0·55	11·42	15·65	4·03	—
Salts	4·4	5·70		7·11	8·39	11·40

The small proportion which the oleaginous bear to the albuminous substances (as in the case of the lymph), in the first three of the preceding analyses, is probably due to the circumstance that in these instances but little food had been taken for some hours before death. The characters of the *Chyle* drawn from the larger absorbent trunks, near their entrance into the Receptaculum chyli, are very different from those of the fluid first absorbed into the Lacteals; for during its passage through these vessels and the Mesenteric glands, it undergoes important alterations, which gradually assimilate it to Blood. The chyle drawn from the lacteals that traverse the intestinal walls contains Albumen in a state of complete solution; but it is generally destitute of the power of coagulation, no Fibrin being present in it. The Salts, also, are completely dissolved; but the Oily matter presents itself in the form of globules of variable size.* It is generally supposed, that the milky colour of the chyle is owing to these; but Mr. Gulliver has pointed out† that it is really due to an immense multitude of far more minute particles, which he describes as forming the *molecular base* of the chyle. These molecules are most abundant in rich, milky, opaque chyle; whilst in poorer chyle, which is semi-transparent, or opaline, the particles float thinly or separately in the transparent fluid, and often exhibit the vivid motions common to the most minute molecules of various substances. Such is their minuteness, that, even with the best instruments, it is impossible to form an exact appreciation either of their form or their dimensions. They seem, however, to be generally spherical; and their diameter may be estimated at between 1-36,000th and 1-24,000th of an inch. Though remarkable for their unchangeableness, when subjected to the action of numerous re-agents which quickly affect the proper Chyle-corpuscles, they are readily soluble in ether, the addition of which causes the whole molecular base instantly to disappear, not a particle of it remaining; whence it may be inferred that they consist of oily or fatty matter. That they do not ordinarily tend to coalesce is probably due to the coating of albumen which they obtain through their diffusion in an albuminous fluid; if, however, this be dissolved by acetic acid, or even by the addition of water, many of the molecules are lost sight of, and oil-drops appear in their place. The milky colour which the Serum of blood sometimes exhibits in healthy subjects is due to an admixture of this molecular base with the circulating fluid.

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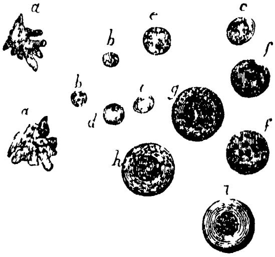
* These oily globules are more abundant in the Chyle of Man and of the Carnivora than in that of the Herbivora; their diameter has been observed to vary from 1-25,000th to 1-2000th of an inch.

† "Gerber's General Anatomy," Appendix, p. 88; and "Hewson's Works" (Sydenham Society Edition), notes to pp. 82-88; and College Lectures in "Med. Times and Gazette," 1863.

125. During the passage of the Chyle through the absorbents on the intestinal edge of the mesentery, towards the Mesenteric Glands, its character changes in several important particulars. The presence of Fibrin begins to manifest itself, by the slight coagulability of the fluid when withdrawn from the vessels; and a few Chyle-corpuscles make their appearance. The diameter of these bodies varies from 1-7110th to 1-2600th of an inch: the average being about 1-4600th. The smallest among them (Fig. 30, *b*, *c*) seem to be in the condition of nuclei; in those a little larger (*d*, *e*), the cell-wall is beginning to be differentiated from the nucleus; whilst in those of greatest diameter (*f*, *g*, *h*, *i*), the cellular character is very distinct, and the nucleus may be plainly seen in the interior, especially after the addition of a little water or acetic acid. They occasionally exhibit curious changes of form (*a*, *a*); in this respect corresponding with the Colourless corpuscles of the blood, which are probably the same bodies in a more advanced stage. A great increase in the number of these corpuscles is apparent in the fluid of the efferent lacteals; and there is also a further augmentation in the proportion of Fibrin.—The Chyle drawn from the lacteals that intervene between the Mesenteric glands and the Receptaculum, possesses a pale reddish-yellow colour; and, when allowed to stand for a time, it undergoes a regular coagulation, separating into *clot* and *serum*. The former is a consistent gelatinous mass, which, when examined with the microscope, is found to include the Corpuscles, each of them surrounded by a delicate film of oil; the Fibrin of which it is principally composed differs remarkably from that of the Blood in its inferior tendency to putrefaction; whence it may be inferred that it has not yet undergone its complete vitalization. The serum contains the Albumen and Salts in

FIG. 30.



Chyle-corpuscles in various phases:—*a*, *a*, stellate form occasionally seen after escape of their contents; *b*, *b*, free nuclei; *c*, a nucleus surrounded by a few granules; *d*, *e*, small cells, some with distinct nucleus; *f*, *g*, larger cells, one with a visible nucleus; *h*, similar cell after addition of water; *i*, similar cell after addition of acetic acid.

solution, and a proportion of the Corpuscles suspended in it. It is curious, however, that considerable differences in the perfection of the coagulation, and in its duration, should present themselves in different experiments. Sometimes the chyle sets into a jelly-like mass, which, without any separation into coagulum and serum, liquefies again at the end of half an hour, and remains in this state. This change takes place in the true coagulum also, if it be kept moist for a sufficient length of time.—The Chyle from the Receptaculum and Thoracic duct coagulates quickly, often almost instantaneously; and few or none of the corpuscles remain in the serum. The fluid drawn from the Thoracic duct, and from the Absorbent vessels which empty their contents into it, is frequently observed to present a decided red tinge, which increases on exposure to the air. This tinge appears to be due to the presence of Red blood-corpuscles in an early stage of formation.* The ordinary corpuscles, moreover, have a more distinctly *cellular* character than have those of the chyle and lymph, and they are of larger size, their diameter usually ranging from about 1-2600th to 1-2900th of an inch: in these particulars, they correspond with the Colourless corpuscles of the Blood; as also in the change they exhibit on the action of acetic acid, which brings into view three or four large central particles.

126. From the observations made by Bidder and Schmidt,† on the quantity of fluid discharged from the thoracic ducts of dogs and cats immediately after death, it is inferred by them that the total amount of mingled lymph and chyle which is daily poured-into the Subclavian vein of Man is no less than 28¾ lbs., or considerably more than the entire mass of the blood,—its solid constituents, however, being not more than from one-fourth to one-third the amount contained in the blood. Of the whole quantity thus discharged, it is estimated that only about 6½ lbs. would be chyle derived from ingested aliment; the remainder being lymph, which has passed-out of the blood-current in the course of its circulation, only to be returned to it again. The quantity of lymph which can be obtained from the head and neck of the dog is estimated by Krause‡ at one-third, and by Weiss§ at one-fifth of the weight of those parts; but these proportions are probably too high for the body generally; other experiments of Weiss showing that it varies from one-fifth (after an abundant supply of milk) to one-twelfth of the total weight.

127. The movement of the fluids taken-up by the Absorbent vessels seems to depend upon a combination of different agencies. The lower Vertebrata are provided with 'lymphatic hearts,' or pulsatile cavities, by which important assistance is given in the onward flow; but no such aid is afforded in Man or in the Mammalia; yet it is obvious that a considerable *vis a tergo* must exist, since, if the thoracic duct be tied, it is speedily distended below the ligature, even to bursting. In the Lymphatics as well as in the Lacteals of the higher animals, the onward course of the contained fluids is, however, probably aided by the contraction of the unstriped muscular tissue in their walls, assisted by the action of the valves; and

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* See Mr. Gulliver's Lecture iii, "Med. T. and Gaz.," vol. ii. 1863, p. 449.

† "Verdauungssafte und Stoffwechsel," §§ 224, 285.

‡ "Zeitschrift f. Rat Med.," N. F., band vii. p. 148.

§ "Dissert. Inaug.," Dorpat, 1860, quoted in Funke, "Physiol.," 4th edit., 1863, p. 396.

to this perhaps we may attribute the emptiness of the absorbent system which usually presents itself some little time after death. Moreover, in all the movable parts of the body, assistance is afforded (as it is to the circulation in the veins) by the occasional pressure exercised upon the lymphatic vessels by the surrounding tissues; for while this pressure is operating it will tend to empty them of their contents, which are only permitted by the valves to pass in one direction; and when the pressure is relaxed, they will be refilled from behind. In the lacteals, special agents for the propulsion of the chyle exist in the muscular fibres contained within the villi, which constitute so many minute force-pumps that are perhaps stimulated to action (as suggested by Schiff) by the irritating properties of the bile. When the lacteal and lymphatic fluids have arrived at the thoracic duct, besides the forces already mentioned, their flow receives an additional impetus from a *vis a fronte* derived in part from the suction-power exerted by the rapid movement of the blood in the subclavian veins, the influence of which may readily be proved experimentally, and partly from the negative pressure exerted upon the walls of the duct during the period of inspiration, the opposing influence of expiration being neutralized by the valves. Noll* found the pressure in the larger lymphatics of the neck in cats and dogs to be equal to that of a column of water varying from ½ to 1½ inch in height (10—30 min.), but it is probably much higher in the smaller vessels. The rapidity of the current in the lymphatics of the neck is stated by Weiss to be about one-sixth of an inch per second.

128. Since the blood-vessels constitute a closed system of canals interposed between the histological elements of the various organs, a continual process of *transudation* must take place through their walls, in order that the fluids appropriate to the nutrition of the different tissues may be supplied in due proportion to their requirements. This effect is probably in part the result of the operation of the laws of Osmosis, which are here made subservient, not only to the passage of the nutrient materials of the blood outwards, but also to the introduction of the products of disintegration into the circulating fluid for the purpose of being ultimately discharged by the excretory organs. But the main agent in the process appears to be the constant and considerable pressure exerted by the blood against the inner surface of the vessels, effecting a filtration of its fluid portions into the irregular cavities and interspaces of the connective tissue, which are now believed to constitute the true origin of the Lymphatics. This view receives support from the experiments of Tomsa, who has shown that the injection of serum into the vessels immediately after death, at the ordinary pressure of the blood, is followed by the filtration of a fluid closely analogous to lymph in its characters, which can readily be obtained from the lymphatic vessels.† And there is abundant evidence to show that those circumstances which tend to increase the pressure in the capillaries, either by forcing more blood into the part,‡ or by prevent-

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* Ludwig, "Physiologie," vol. ii p. 581.

† The Serum used in Tomsa's experiments contained from 6·77 to 6·26 per cent of solid residue, and that obtained from the Lymphatics from 6·12 to 4·36 per cent, which is about the proportion in ordinary lymph.

‡ As was effected by Mr. Robinson in his experiment recorded in the "Med.-Chir. Trans.," vol. xxvi. p. 51, when the Aorta just above its division into the common iliacs, and also one of the renal arteries, were tied, and albumen immediately made its appear-

ing its return by ligature or pressure applied to the veins (provided that complete stoppage of the current of the blood is not produced), are followed by an increased discharge of lymph from the larger absorbent vessels. It is easily intelligible that various other causes besides pressure may influence the quantity and quality of this fluid, which, as Milne-Edwards* observes, is poured forth to *irrigate* the various organs of the body; for besides the important condition of the quality of the blood (with the effects of variations in which we are but imperfectly acquainted), differences in the thickness of the walls of the vessels and of the external pressure to which they are subjected, may to some extent be the causes of those differences in the nature of the transudate observed in Hydrocephalus, Ascites, and Hydrocele.†—The influence of the Nervous system on the formation of lymph has been studied by Krause and Tomsa; from whose experiments the conclusion may be drawn, that the nervous system exerts little or no direct, but frequently a well-marked indirect influence on the amount produced in a given time. Thus, whilst Tomsa found that irritation of the nerves proceeding to the testicle produced no alteration of the quantity, Krause observed, on excitation of the portio dura, a considerable increase in the flow; the difference being clearly the result of the intermittent pressure of the muscles in the parts traversed by the lymphatics in the one instance, and the entire absence of muscles in the other.

129. VASCULAR OR DUCTLESS GLANDS.—There is reason to believe that the office performed by certain bodies connected with the Sanguiferous system, which possess the essential elements of the Glandular structure without any efferent ducts, is to restore to the circulating current any substances which they may withdraw from it; and there seems adequate ground, therefore, for the conclusion, that their action, whatever it may be, is subsidiary to the process of Sanguification,—being exercised, perhaps, upon that portion of the nutrient materials more especially, which did not traverse the Absorbent system when first introduced, but which was directly taken-up by the Blood-vessels. The organs in question are the Spleen, and the Thymus, Thyroid, and Supra-renal bodies. Of these, the Spleen deserves especial notice, on account of its size and its obvious functional importance in the adult; the others appearing to minister more particularly to the requirements of the system at the earlier periods of life.

130. The minute structure of the *Spleen* has recently been made the subject of careful research by many excellent Microscopic observers; and the following are the most important points which may be considered to have been established by their labours:‡—

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ance in the urine, being as it were forced by the increased pressure in the remaining renal artery, through the delicate filter formed by the walls of the vessels in the Malpighian tufts.

* See his excellent chapter on Transudation in the "Leçons sur la Physiologie," vol. iv. 1859, p. 391—446.

† See Hale's "Hæmastatus," pp. 118-119.

‡ See Kölliker, "Cyclopædia of Anatomy and Physiology," vol. iv., Art. 'Spleen;' and "Mikroskopische Anatomie," band ii. §§ 183-189. Sanders, "Goodsir's Annals of Anatomy and Physiology," No. 1; and "Edin. Monthly Journal," March, 1852, p. 286. Wharton Jones, "Brit. and For. Med.-Chir. Review," vol. xi. p. 32. Huxley, "Quarterly Journal of Microscopical Science," vol. ii. p. 74; and Translation of Kölliker's "Manual of Human Histology" (Sydenham Society), vol. ii. p. 144. Gray, "On the Structure and Use of the Spleen" (Astley-Cooper-Prize Essay, 1854). Remak,

I. The *fibrous coat* in Man is composed of white fibrous tissue, with an intermixture of yellow or elastic fibres, and perhaps a few fusiform non-striated muscular fibre-cells; which, however, are much more numerous in many of the lower animals. The *trabecular tissue* consists of bands and threads of fibrous tissue, which arise from the inner surface of the fibrous envelope, and form a network that extends through the entire organ, becoming connected also with the fibrous sheaths of the vessels which penetrate it. These bands are partly muscular in those animals which have muscular fibres in the external envelope; but elsewhere they are simply fibrous. The spaces left by their intersection, which are by no means regular as to either form or size, are occupied by the splenic corpuscles and splenic parenchyma.

II. Of the *Arteries* of the Spleen, it is chiefly to be observed that their branches form no anastomoses, but subdivide and ramify like the branches of a tree, with the Malpighian corpuscles attached to them as fruit (Fig. 31). Beyond their connection with these, however, they enter the general mass of the splenic parenchyma; and here each twig subdivides into a tuft of arterioles still more minute, which again subdivide into the true capillaries.—The *Capillaries*, bounded only by their very thin walls, pass in every direction through the spleen-pulp, both in the general mass of the organ, and also in the interior of the Malpighian corpuscles. But it is affirmed by Mr. Gray, that in the Spleen of Man and of many other animals, the walls of the capillaries frequently disappear, and that the blood, in passing from the minutest arteries to the minutest veins, moves in great part through *lacunæ*, or mere channels in the pulp-tissue.—Of the *Veins*, the idea has been generally entertained, that they are dilated into cavernous spaces or sinuses; but this, though true of many of the lower Mammalia, especially of ruminants and diving animals, is the case to only a very limited extent in Man. Their mode of ramification closely resembles that of the arteries; and they are unprovided with valves.

III. The *Parenchyma* of the Spleen essentially consists of cells in various stages of evolution, imbedded in a granular plasma; thus corresponding in every essential particular with the contents of the Peyerian and Absorbent glandulæ (§ 122), and giving evidence, as they do, of being in a state of rapid developmental change. The amount of this colourless parenchyma is stated by Mr. Gray to undergo a marked increase towards the end of the digestive process, when a large quantity of new alimentary material is being introduced into the sanguiferous current; whilst, in the intervals of this operation, it undergoes a gradual diminution.—The peculiar *Splenic Corpuscles*, or 'Malpighian bodies of the Spleen,' are whitish spherical bodies, which are connected with the smaller arteries by short peduncles, like grapes with their fruit-stalks, or are sessile upon their sheaths (Fig. 31). Their diameter usually varies between 1-3rd and 1-6th of a line; smaller bodies, however, are met with, which appear to be Malpighian corpuscles in an earlier stage of

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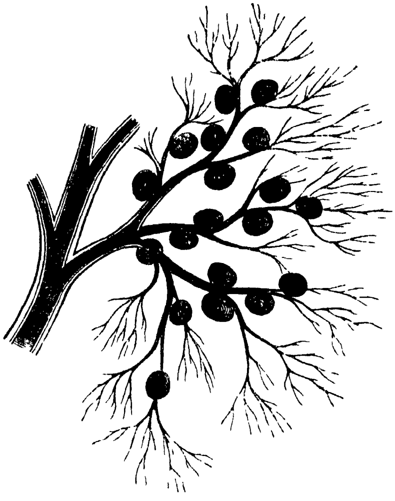
'Ueber runde Blut-gerinnsel und über Pigment-kugelhaltige Zellen,' in "Müller's Archiv," 1852. Leydig, "Anatomische-Histologische Untersuchungen über Fische und Reptilien," 1853. Billroth, "Archiv fur Pathologische Anat.," band xx. p. 409 and 528; "Archiv f. Anat. und Physiolog.," 1857, p. 88. Kowalowsky, "Virchow's Archiv," 1861, p. 203.

Fig. 31.



Branch of *Splenic Artery*, the ramifications of which are studded with *Malpighian corpuscles*.

evolution. The boundary of each is an indistinctly-fibrous membrane, which appears to be partly formed by the metamorphosis of the external cells of its contained parenchyma, and to be partly derived from the fibrous coat of the artery to which it is attached.[*] And its contents correspond, in every essential particular, with the colourless parenchyma in which they are imbedded. Their walls are covered with a plexus of capillaries, and branches from these traverse their interior, just as in the case of the Peyerian and Absorbent glandulæ. The number and size of the Malpighian corpuscles bear a remarkable relation to the general state of nutrition; being much the greatest in healthy well-fed animals, whilst in those that have been ill-fed they diminish extremely, and in those that have been starved they disappear altogether. Hence it has happened that their existence in the Human species has been denied; the opportunity of examining subjects not reduced by previous abstinence, being one that comparatively seldom occurs. There is no doubt, however, of their normal presence in the spleen of Man, as in that of other Mammalia.—Diffused amidst the colourless parenchyma, but in very variable amount, *coloured* cells are found, some of which are unchanged blood-corpuscles, whilst others appear to be blood-discs in various stages of retrograde metamorphosis; gradually diminishing in size, and assuming a golden-yellow, brownish-red, or even blackish colour, or having the pigmentary matter crystallized in a rod-like form in their interior; or, again, breaking-up into detached pigment-granules. Occasionally (though very rarely in the Human subject) little clusters of from 1 to 20 of these degenerating blood-corpuscles are found, included in a vesicular envelope. All these bodies are seen in the blood of the Splenic vein; and it has been hence concluded by some, that they do not constitute normal elements of the Splenic parenchyma, but that they are either contained in its capillaries, or, if actually diffused through the pulp, are so as a result of an abnormal extravasation. These conflicting views may be reconciled, if, as stated by Mr. Gray, the splenic blood, in its passage from the arteries to the veins, normally escapes from the walled vessels into indefinite channels, traversed by connective tissue (Billroth), so that its corpuscles may become diffused through the parenchyma without any departure from its regular course; and it is a confirmation of this view, that the amount of *coloured* corpuscles in the spleen-pulp augments with the general turgescence of the vascular system, and diminishes with the poverty of the blood, so that, in animals reduced by ill-feeding, it disappears altogether.

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[*] It has been commonly supposed that the Malpighian corpuscles are invested by a distinct limitary membrane, like the *acini* of ordinary Glands; but such, from the observations of Wharton Jones and Huxley, would clearly seem to be not the case.

IV. The *Lymphatics* of the Spleen are few and inconsiderable in Man; being less numerous than in other glandular organs, such as the liver and kidneys. In some of the lower animals, they are more abundant; but even here they are mostly superficial, and scarcely penetrate to the interior of the organ.

V. The *Nerves* of the Spleen are apparently very large in some animals, especially in the Ruminants; but the great size of their trunks and branches is chiefly due to the large proportion of ordinary fibrous tissue which enters them; the number of real nerve-fibres being extremely small.

VI. The chemical composition of the Spleen is indicated by the following analysis of Oidtmann:—In 1000 parts were, water, 750·31, solid residue, 249·69; of the latter, 242·32 parts were organic substances, and 7·37 inorganic. Amongst the organic substances, albumen, fats, inosite, uric acid, sarkine, xanthine, leucine, tyrosine, and pigment have been distinguished. The most remarkable circumstances respecting the inorganic constituents are the large relative quantity present of soda, salts, and of oxide of iron.* From the observations of Mr. Dobson,† which have been corroborated by other observers, it appears that the Spleen attains its maximum volume at the time that the process of chymification is at an end, namely, about five hours after food is taken; and that it is small and contains little blood seven hours later, when no food has been taken in the interval. The removal of this organ from the body has frequently been performed in animals without serious effects; in some instances perfect regeneration has occurred, which is probably attributable to the hypertrophy of the little splenculi so often present in the immediate vicinity of the Spleen;‡ in others, enlargement of the lymphatic glands in various parts of the body, as the neck and axillæ, has been observed. Maggiorani§ has noticed a deficiency in the amount of iron contained in the blood-corpuscles; and in the dogs operated on by Dr. Dalton‖ an unnatural appetite and a ferocity of disposition were exhibited.

131. The history of the *development* of the Spleen, which has been recently studied with much care by Mr. Gray,¶ presents facts of great interest, as aiding in the determination of the functional character of this organ, and of the nature of its component parts.—It arises in the Chick between the 4th and 5th days of incubation, in a fold of membrane which connects the intestinal canal to the spine (the 'intestinal lamina'), as a small whitish mass of blastema, perfectly distinct from

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* v. Gorup-Besanez, "Physiolog. Chemie," 1862, p. 660.

† "Lond. Med. and Phys. Journ.," Oct., 1820.

‡ Phillipeaux and Mayer, "C. Rendus," 1861, p. 547.

§ "Comptes Rendus," 1861, p. 319.

‖ "Human Physiology," 1862, p. 193.

¶ 'On the Development of the Ductless Glands in the Chick,' in "Philosophical Transactions," 1852, p. 295; see also his Prize Essay.

both the stomach and the pancreas; from the former of which it has been said by Bischoff, and from the latter by Arnold, to take its origin. The external capsule and the trabecular tissue are developed between the 8th and 9th days: the former as a thin membrane composed of nucleated fibres; the latter consisting of similar fibres, which intersect the organ at first sparingly, and afterwards in greater quantity. The blood-vessels of this organ are formed within itself, independently of those which are exterior to it; and blood-corpuscles are also observed to originate in the substance of its blastema, their formation continuing until its connection with the general vascular system is completed, at which period their development appears to cease.—The pulp-tissue, at an early period of its formation, closely corresponds with that of the Supra-renal and Thyroid bodies in their earliest stages of evolution; consisting of nuclei, nucleated vesicles, and a fine granular plasma. When the splenic vessels are being formed, many of these nuclei are surrounded by a quantity of fine dark granules, arranged in a circular mode; and these appear to be developed into nucleated vesicles, of which, when the splenic vein is formed, nearly the whole pulp is composed; the nuclei of these subsequently break-up into a mass of granules, which fill the cavities of the vesicles. The Malpighian corpuscles are developed in the pulp, at the angles of division of the smaller blood-vessels, by the aggregation of nuclei into circular masses, around which a fine membrane is subsequently formed.—Thus during fœtal life we have evidence of a process of cell-growth and maturation, followed by cell-destruction, in the colourless parenchyma. The largest proportional size and the greatest functional activity of the Spleen, however, seem to be exhibited during adolescence and the most vigorous period of adult life.

132. The *Supra-Renal* bodies in Man and most Mammalia, present, like the Kidneys, a division into cortical and medullary substances; the former having a lighter hue than the latter.—The *cortical* substance is principally formed of a stroma of connective tissue, so arranged as to leave a series of oval spaces, lying end to end;* which spaces are filled with a finely-granular plasma, containing a large amount of fat-particles, with nuclear corpuscles, and more or less completely-formed cells. Isolated cells of a larger size are found in the stroma of the inner part of the cortex, in which the linearly-arranged spaces do not exist.—The *medullary* substance consists of a basis of fibrous tissue, which is formed by processes that come-off from the sheath of the cortical substance, and which contains numerous blood-vessels and nerves. The interspaces of this tissue, however, are occupied by a granular plasma, in which are nuclei and cells in various stages of development; and the recent observations of Kölliker upon the nature of these cells, which are confirmed by the researches of Leydig (op. cit.) upon the corresponding organs in the Amphibia, seem to indicate that they are really *ganglionic* in their character. Both the cortical and the medullary substances receive a large supply of blood.

133. Though Brown-Séquard† found that ablation of the Supra-

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* This is the account given by Kölliker ("Mikroskopische Anatomie," § 220), who confidently states that the spaces are not bounded by a proper limitary membrane, and are therefore not gland-vesicles, as supposed by Ecker and Frey, whose views of their nature will be found in the Art. 'Supra-Renal Capsule' in the "Cyclop. of Anat. and Physiol.," vol. iv.

† "Journal de la Phys.," vol. i., 1858, p. 160.

renal Capsules was uniformly fatal, yet Phillipeaux,* Harley,† and Gratiolet‡ have shown that this effect is rather attributable to hæmorrhage and the unavoidable injury to the nerves, and especially to the semilunar ganglia, attendant upon the operation, than, as Brown-Séquard believed, to the retention of some poisonous substance in the circulation, which it is the office of these bodies to remove. Of late years much importance has been attached to the study of the diseases of these organs, from the observations of Dr. Addison, that such cases are frequently associated with the deposition of pigment in the skin, causing it to assume a deep bronze colour. Harley, Parkes, and many others have, however, shown that bronzing of the skin may be present and yet the supra-renal capsules be healthy;§ whilst Dr. Kirkes, Davy, and others have recorded cases in which disease was present in one or both of these organs, yet no bronzing of the skin occurred.‖ Further inquiry is therefore requisite to determine whether the disease of the capsules and the discoloration of the skin really stand in the relation of cause and effect.

134. The *development* of the Supra-Renal bodies also has been studied by Mr. Gray (loc. cit.). He states that they arise on the 7th day of incubation, as two separate masses of blastema, situated between the upper end of the Wolffian bodies and the sides of the aorta; being totally independent (as concerns their development) of those bodies and of each other. At this period, their minute structure bears a close resemblance to that of the spleen, consisting of the same elements as that gland, excepting in the existence of more numerous dark granules, which give to the organ at a later period an opaque and darkly-granular texture; and the general history follows a very similar course: the Supra-renal capsules, however, acquiring their characteristic structure, and attaining their largest relative size, so early in fœtal life, as to surpass the Kidneys in dimension up to the tenth or twelfth week of Human embryonic development; though they afterwards diminish so much, relatively to the Kidneys, as to possess in the adult condition only 1-28th part of their bulk.

135. The general structure of the *Thymus* Gland may be best understood from the simple form it presents, when it is first capable of being distinguished in the embryo. It is then solid,¶ but soon breaks down in the central part so as to form a single tube, closed at *both* ends, and filled with granular matter; and its subsequent development consists in the lateral growth of branching off-shoots from this central tubular axis. In its mature state, therefore, it consists of an assemblage of hollow glandular lobules, united together by connective tissue; and their cavities all communicate with the central reservoir, from which, however, there is no outlet (Figs. 32, 33). Each lobule is bounded externally by an indistinctly-fibrous or almost homogeneous membrane (Fig. 34, *a*), which sends prolongations (*b*) into its substance, that divide it into 'acini' or gland-granules. Isolated gland-granules of the same kind are frequently to be met-with on the main canal (Fig. 32, *c*.). The parenchyma of each lobule is made-up of a greyish-white,

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* "Comptes Rendus," 1856-57.

† "Med.-Chir. Rev.," 1858, vol. i. p. 209.

‡ "Comptes Rendus," 1856.

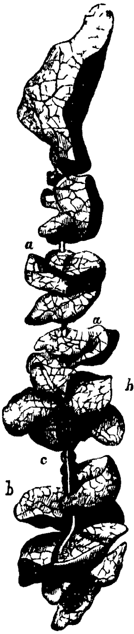
§ "Med. T. and Gaz.," 1858, p. 564.

‖ "Med. T. and Gaz.," 1857, p. 35; 1859, p. 30.

¶ Jendrassik, "Sitzungsbericht d. Wien Akad.," 1856, band xxii. p. 75.

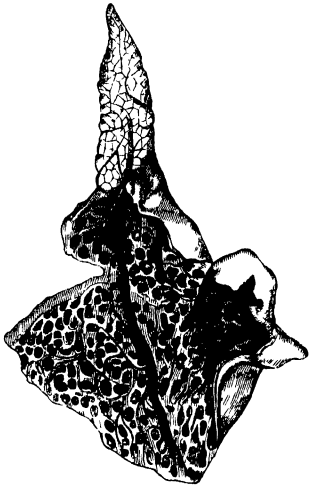
soft, easily-lacerable substance, which, when examined microscopically is found to consist of free nuclei and minute cells; and it is traversed b a minutely-distributed capillary plexus; thus resembling, in every respect save the presence of a central cavity, that of the Peyerian bodies (§122).*

FIG. 32.



Portion of *Thymus* of *Calf*, unfolded —*a*, main canal; *b*, glandular lobules; *c*, isolated gland-granules seated on the main canal.

FIG. 33.



Section of *Human Thymus*, showing the large cavity in the wide portion, and numerous orifices leading to its lobular cavities

Cells and nuclei resembling those of the parenchyma are also found in th cavity of the lobule;† from which, indeed, the parenchyma is not separate by any distinct limitary membrane. The chemical constituents of th *Thymus* are water, albumen, gelatine, sugar, fats, leucine, sarkine, xanthic formic, acetic, succinic, and lactic acids, and the ordinary inorganic salts. —The Vascular supply of this organ, during the period of its function activity, is extremely abundant. The arterial trunks penetrate to it central cavity, and form a close reticulation in the delicate pellicle c connective tissue with which it is lined; from the several points at whic the lobular cavities open, numerous vessels arise from this plexu

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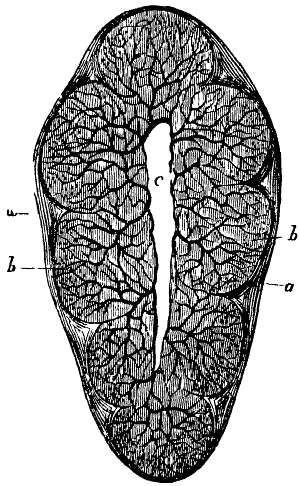
* See Prof. Kolliker's "Mikroskopische Anatomie," § 208, from which the abov account is chiefly derived; also Mr. Simon's "Physiological Essay on the Thymus Gland.

† See Mr. Gulliver's Lecture iv., "Med. Times and Gaz.," 1863, vol. ii. p. 503.

‡ See Friedleben, in the "Journal de la Physiologie," 1859, p. 137; and v. Goru Besanez, "Phys. Chemie," 1862, p. 666.

(Fig. 34), passing along their internal surface; and from these is derived the capillary plexus which traverses the substance of each gland-granule, but which does not pass as far as its external surface, returning by loops before it reaches its fibrous envelope. The Lymphatics of the Thymus are large, and communicate directly with the Vena Cava; but their immediate connection with the cavity of the Thymus body, though highly probable, has not been demonstrated.—It has been commonly stated, that the Thymus attains its greatest development, in relation to the rest of the body, during the latter part of fœtal life; and it has been considered as an organ peculiarly connected with the embryonic condition. But this is a mistake; for the greatest activity in the growth of this organ manifests itself, in the Human infant, soon after birth; and it is then, too, that its functional energy seems the highest. This rapid state of growth, however, soon subsides into one of less activity, which merely serves to keep-up its proportion to the rest of the body; but its increase is continuous till the age of puberty is attained (Friedleben). From that time, during a variable number of years, it remains stationary in point of size; but, if the individual be adequately nourished, it gradually assumes the character of a mass of fat, by the development of the corpuscles of its interior into fat-cells, which secrete adipose matter for the blood. This change in its function is most remarkable in hybernating Mammals; in which the development of the organ continues, even in an increasing ratio, until the animal reaches adult age, when it includes a large quantity of fatty matter. The same is the case, generally speaking, among Reptiles.

Fig. 34.



Transverse section through an injected lobule of the *Thymus* in a child:—*a*, membranous investment of the lobule; *b*, membrane of the gland-granules; *c*, cavity of the lobule, from which the larger vessels branch-out.

136. The *Thyroid* body differs from the other Vascular Glands in its elementary structure; for it essentially consists of an aggregation of closed vesicles (Fig. 35, *b*, *b*), which seem to be furnished with a true limitary membrane, and therefore to be real gland-vesicles, imbedded in a stroma (*a*, *a*) of connective tissue, and not communicating with any common reservoir. These bodies vary in diameter, in the Human subject, from 1-2000th to 1-85th of an inch; and they contain an albuminoid plasma,* which is either faintly granular or of a somewhat oily aspect, amidst which are seen a number of corpuscles, the greater part of them in the

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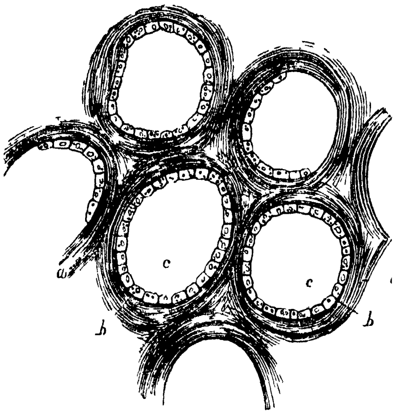
* That the fluid does *not* contain true Albumen in solution, but some albuminous compounds, is indicated by the results of Dr. Beale's analysis ("Cyclop. of Anat. and Physiol.," vol. iv. p. 1106).

condition of nuclei, whilst some have advanced to that of cells. These corpuscles, however, seem rather to occupy the position of an epithelium (*c, c*) within the vesicles, than to float freely in their contained fluid.—The vascular supply of the Thyroid body is extremely abundant; and, as in the preceding instances, the subdivisions of its arteries form a very minute capillary plexus upon the membrane of the vesicles. The Lymphatics, though abundant, have not been traced far into its substance.—The Nerves are scanty, accompany the vessels, and are derived from the cervical parts of the sympathetic.—The development of the Thyroid body has been shown by Mr. Gray (loc. cit.) to be closely accordant with that of the 'ductless glands' already described. This body originates in two separate masses of blastema, one at each side of the root of the neck, close to the separation of the carotid and subclavian vessels, and between the trachea and the branchial clefts, but quite independent, as far as regards their development, of either of those parts; their minute structure at an early period closely corresponds with that of the spleen and supra-renal glands. This body, like the Supra-renal and Thymus, is of larger relative magnitude during intra-uterine existence and infancy, than in after-life.

FIG. 35.



Group of gland-vesicles from the *Thyroid Gland* of a Child —*a*, connective tissue, *b*, membrane of the vesicles, *c*, epithelial cells.

137. That the Ductless or Vascular Glands,* of whose peculiar structure and relations we have thus taken a general survey, have some office of importance to perform in the preparation and maintenance of the blood, cannot any longer be reasonably questioned; and the determination of this point may be fairly regarded as a considerable step in the investigation. It is obvious, from the very copious supply of blood which they receive during the period of their functional vigour, and from the manner in which this is distributed by minute capillary plexuses, on the exterior, and even through the interior, of the glandular vesicles, that it must be subservient to some process of active change; and the aspect of the contents of these vesicles, as well as of the substance in which they are imbedded, indicates that cell-growth is rapidly proceeding, at the expense of the materials thus afforded. But, on the other hand, that the products

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* According to Ecker (Art. 'Blutgefässdrusen' in "Wagner's Handworterbuch," band iv.), the Pituitary body has the same essential structure as the vascular glands in general; having vesicles containing a finely-granular blastema, with nuclear particles, imbedded in a fibrous stroma.

of this cell-growth are *not* substances, which, like those of the ordinary glands, must be separated from the blood, either for *its* purification, or to serve some special purpose in the economy, appears from the fact that they are not carried-off by ducts; but are received again into the current of the circulation. With the exception of the Spleen, all the ductless glands thus discharge their products at once into the general venous circulation; so that, after having passed through the lungs, they will be carried by the systemic arteries through the system at large: but the splenic vein, it will be remembered, forms one of the roots of the portal trunk; and *its* blood must thus pass through the *liver*, before it enters the vena cava.

138. Whatever materials, then, are withdrawn from the blood by these organs, are returned to it again in an altered state; and it may fairly be inferred from this circumstance, that the change which they have undergone is one that prepares them for higher uses in the economy. For as the blood which has received them is immediately transmitted to the system (except in the case of the splenic blood), without having passed through any other depurating organ than the lungs, it appears fair to conclude that the products which it has taken-up in these organs are either *combustive* or *nutritive*, *i.e.*, either serve to maintain the functional activity of the lungs, or of the system, or of the blood itself. Now that they are not destined to prepare a pabulum for respiration, appears from the very small quantity of fat which is found in their substance, except when their period of functional activity has gone-by. On the other hand, the albuminous nature of the plasma, and the finely-granular appearance which it presents, strongly indicate that a material is here in progress of preparation, which is to be rendered subservient to the formative operations. Various facts which have been noticed in regard to the changes in the bulk of the Thymus in young animals (and particularly its rapid diminution in over-driven lambs, and its subsequent gradual re-distension during rest, if plentiful nutriment be afforded), lead to the conclusion that such is almost undoubtedly the function of that body. And such would also seem to be the justifiable inference from the researches of Mr. Gray on the Spleen: for the correspondence in the amount of the colourless parenchyma of that organ (and especially of its Malpighian corpuscles) with the general state of nutrition of the animal, its regular increase (in well-fed animals) near the completion of the digestive process, and its gradual diminution in the subsequent interval, seem to indicate that the Spleen, like the Thymus of the young animal, is a storehouse of nutritive material, which may be drawn-upon according to the requirements of the system, just as the fat of the body is a storehouse of combustive substance. And of the exertion of an elaborating or assimilative action upon this albuminous matter, during its withdrawal from the current of the circulation in these organs, we seem to have direct evidence, as regards the Spleen, in the large increase of the proportion of fibrin contained in the blood drawn from its veins. It was formerly supposed that the Spleen acted as a kind of reservoir or diverticulum for the portal circulation, the vessels of which were thus relieved from undue turgescence, when the alimentary canal was distended with food, and rapid absorption was taking place. Others again were of opinion that a process of disintegration took place in the blood-corpuscles

which are found so abundantly in the splenic pulp, but the grounds on which both these views were supported are scarcely tenable in the present state of our knowledge.*

139. The results then of all the recent investigations on these organs tend to prove that, equally with the Absorbent glands, they supply the germs of those cells which are ultimately to become blood-corpuscles. Such, it is well known, was the doctrine of Hewson† in regard to the Spleen and Thymus gland; and there are many facts which lend it a considerable probability. In the first place, we have seen (§ 130, II.) that there is no difficulty whatever in the admission of such corpuscles into the smaller veins of the Spleen, if Mr. Gray's account of its lacunar circulation, which appears to be fully confirmed by the more recent investigations of Billroth,‡ be correct; and that there is no physical impossibility in the reception of particles of such a size into the interior of even a closed system of capillaries, is proved by the very curious facts already noticed in regard to the passage of starch-grains into the mesenteric veins (§ 114). Secondly, there is an unusual proportion of colourless corpuscles in the blood of the splenic vein.§ Thirdly, the period of greatest functional activity of these glands generally, is during the state of early childhood, when the formative processes are going-on with extraordinary activity; and there is at this time a larger proportion of colourless corpuscles in the blood, than at any subsequent period, at least in the healthy state. Further, as Prof. J. H. Bennett has pointed-out, that peculiar condition of the blood, which consists in the multiplication of its colourless corpuscles, is almost always associated with hypertrophy of one of these bodies; and in one case of this kind, in which the Thyroid was the organ affected, its cells and their included nuclei were observed to be considerably smaller than usual, and the same peculiarity presented itself in the colourless corpuscles of the blood.‖ Hence there seems a strong probability, that whilst the plasma of the blood is being elaborated by these bodies, a constant supply of new blood-corpuscles is also afforded by them;¶ and that they thus effect for the nutrient materials directly absorbed into the Sanguiferous system, that which the glandulæ in connection with the Absorbent system accomplish for the substances which *it* has taken-up.

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* See "Cycl. of Anat. and Physiology," vol. iv. p. 796.

† See his Third Series of "Experimental Inquiries," chaps. iii.–v.

‡ "Müller's Archiv," 1857, p. 88, and "Virchow's Archiv," band xx. p. 410.

§ See Funke in "Henle's Zeitschrift," 1851, p. 172; and Gray, Op. cit., p. 148.

‖ This fact is the more weighty, as, in another case observed by Prof. Bennett, the colourless corpuscles of the blood were of two distinct sizes, the smaller corresponding with the nuclei of the larger ones; and the *lymphatic glands* were found to be crowded with corpuscles also of two distinct sizes, exactly corresponding with those of the blood. (See "Edinb. Monthly Journal," October, 1851.)

¶ This view has been ably supported by Prof. J. H. Bennett, in "Edinb. Monthly Journ.," March, 1852; and in his Treatise on "Leucocythæmia."

CHAPTER V.

OF THE BLOOD; ITS PHYSICAL CHARACTERS, ITS CHEMICAL COMPOSITION, AND ITS VITAL PROPERTIES.

1. *General Considerations:—Quantity of Blood.*

140. From the materials supplied in the Food, there is prepared, by the Digestive and Assimilative processes described in the preceding Chapters, that general nutritive liquid, the *Blood*, which, in the organism of Man (as in that of all the higher Animals) is constantly circulating through its vessels during the whole of life. From this liquid, each portion of the solid tissues has the power of extracting, and of appropriating to its own use, the particular components of its substance; these either pre-existing as such in the blood, or being capable of being readily formed from it by a process of chemical transformation. During its circulation, moreover, the blood draws into its current the effete particles which are set-free by the disintegration of the tissues (probably at the very time when it gives-forth the components of the newly-forming structures), and conveys them to the various organs which are provided for their elimination. Hence the Blood not only contains the materials for the renovation of the tissues, but also the products of their decay: but there is an important difference in the proportion of these two sets of components; for whilst the former make-up the principal part of the mass of the fluid, the latter are only detectable in it with difficulty, so long as the excretory organs maintain their normal activity; and only make their presence obvious, when they accumulate unduly, in consequence of the retardation or suspension of the eliminating operations.—But besides thus meeting the demand occasioned by the *constructive* operations, and preventing the results of the *destructive* from exerting an injurious influence on the system, the Blood acts (so to speak) as the carrier of Oxygen introduced from the atmosphere, to the Muscular and Nervous tissues, to whose peculiar vital activity its presence appears to be an essential condition, the same element being also required in various other metamorphoses which form part both of the constructive and of the destructive operations: whilst conversely it imbibes the Carbonic acid, which is one of the chief products of the action of oxygen upon the tissues and fluids of the body, and conveys this to the lungs and skin for elimination. This product is continually being formed in such large amount, that its presence in the blood can always be readily demonstrated; and if its elimination be checked for even a few minutes, it accumulates to such an extent as to occasion the immediate destruction of life.—But in addition to the Histogenetic materials and Oxygen, on the one hand, and the various products of the disintegration of the tissues on the other, the blood contains those non-azotized substances, which are received into it for the purpose of supplying the *pabulum* of the Combustive process; and the union of their carbon with oxygen introduced from the atmosphere, which is continually going-on, becomes an additional source of the production of carbonic acid, and of its injurious accumulation if its elimination be checked.

141. From this variety in the operations to which the Blood is subservient, it naturally follows that the changes which it undergoes in different parts of its circulation are of a very diversified nature, and that the composition of the fluid in the several parts of its course will be far from uniform. Between the blood which is being distributed by the systemic Arteries to the body at large, and that which is being collected from it again by the systemic Veins, after having percolated the tissues, there is not only an obvious difference in hue, which indicates an important change, but there is also a considerable difference in composition, which is revealed by chemical analysis: and a difference of a converse nature presents itself, between the blood that is on its way to be distributed to the Lungs, and that which is returning from them. So, again, although there is no obvious dissimilarity in physical characters between the blood which is transmitted to the Liver by the vena portæ, and that which is carried-off from it by the hepatic vein, yet chemical analysis reveals a very remarkable difference in their composition, and shows that the blood of the ascending vena cava (above the entrance of the hepatic vein), that of the right cavities of the heart, and that of the pulmonary artery, differs from all other blood in the body, in constantly containing an appreciable quantity of a peculiar substance readily convertible into sugar, which is formed in its passage through the Liver. In like manner the researches of M. Picard have shown that the blood of the renal vein contains a smaller proportion of the chief component of the urinary secretion, urea,* than that of the renal artery; and in many other cases of blood returning from particular organs we know that important differences must exist, although they have not yet been detected by chemical analysis.—In the account to be presently given of the Blood, those most general characters and properties will be first described, which it presents in all parts of its circulation; the principal differences which have been substantiated in the composition of the blood in the several portions of its circuit, will then be noticed; and, lastly, a summary will be given of the most important of those pathological alterations which it exhibits in disease.

142. The quantity of Blood contained in the Human body is probably, for a man of average height, from 12 to 15 lbs.; but its precise determination is more difficult than might at first be supposed, and the estimates which have been made of it have been most strangely discrepant. The entire amount which flows from a large arterial trunk freely opened, can by no means be taken as a measure; since, however readily it may be permitted to escape, a considerable quantity still remains within the blood-vessels, especially if the heart's action fail before the loss of blood has proceeded very far, so that it is not drawn from the venous system. A closer approximation may be made by opening several vessels at once, which was the method adopted by Herbst;† who estimated the proportion of the weight of the blood to that of the entire body to be as 1 : 12 in the Ox, as 1 : 16 in the Dog, as 1 : 18 in the Horse, as 1 : 20 in the Goat, Calf, Lamb, and Hare, as 1 : 22 in the Sheep and Cat, and as 1 : 24 in the Rabbit. With these estimates the conclusions drawn by Vanner, from observations made in

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* C. Bernard, "Leçons," 1859, vol. ii. p. 31; Picard, "Thèse sur l'Urée," 1856.

† "De Sanguinis quantitate, qualis homini adulto et sano convenit." Goettingæ, 1822.

the *abattoirs* of Paris, pretty closely correspond ; for he was led by them to the belief, that for horned cattle in general, the proportion does not vary far from 1 : 20.[*] It is obvious, however, that no such method can give more than a *minimum ;* since, even after the most complete exsanguination that the freest opening of the vessels can permit, a considerable quantity of blood is still retained in them, and especially in those of the head. Various other methods have been suggested, none of which, however, can be considered as yielding more than approximations to the truth. That of Vierordt[†] consists in multiplying the quantity of blood which is expelled from the left ventricle at each pulsation of the heart by the number of beats which occur whilst the blood performs one entire circuit of the body. He estimates the former (highly) at 6·3 oz. av., and the latter at 27·7 beats; consequently the total quantity of blood is about 12 lbs. av., or between one-twelfth and one-thirteenth of the weight of the body. Welcker's method, termed also the "chromatic" or "colour" method, gives nearly the same result for the Dog. It consists in first roughly estimating the quantity of blood in the animal by rapidly bleeding it to death. The portion that still remains in the small vessels is then removed by the injection of pure water, and the whole body of the animal is finely minced and infused. These liquids are mingled, and on comparing their tint with a series of previously prepared "colour tests," the proportion of blood in which is accurately known, a practised eye may discern variations in the colour when the difference in the quantity of blood does not exceed 4 per cent. An interesting collection of cases has been brought together by Haller[‡] of the amount of blood lost by hæmorrhage; and two remarkable instances are cited by Burdach,[§] from Wrisberg, who states that a female who died from violent metrorrhagia had lost 26 lbs. of blood, and that 24 lbs. were collected from the body of a plethoric female who had suffered death by decapitation. In the first of these cases, it is probable that, as death could not have been *immediate*, some increase took place from the absorption of the fluids of the body ; in the second, however, the suddenness of the discharge of blood, and its concurrence with the destruction of life, must have prevented any considerable augmentation from this source; and if any such increase did take place, it probably did not exceed the amount of blood remaining undischarged in the vessels. An important observation has been made by Bernard,[||] that the quantity of blood which can be obtained from a fasting animal is scarcely more than one-half of that contained in its vessels shortly after a full meal : a point to which no other observer appears to have hitherto paid attention, but which may account for some of the discrepancies observable in the different estimates.[¶]

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[*] "Comptes Rendus," tom. xxviii. p. 649.

[†] "Physiologie," 1861, p. 113.

[‡] "Elementa Physiologiæ," vol. ii. pp. 3 and 4.

[§] "Traité de Physiologie," traduit par Jourdain, tom. vi. p. 119.

[||] "Leçons," 1859, t. i. p. 419.

[¶] Valentin's method is founded on the diminution in the specific gravity of the blood after the injection of a known weight of water into the vessels, and gave for dogs the proportion of the weight of blood to that of body generally as 1 : 4½ ("Repert. f. Anat. und Phys.," band iii. p. 281). Blake's method consisted in the injection of a definite quantity of some saline compound, as sulphate of alumina, and its subsequent quantitative determination, in a portion of blood drawn from another part of the system. This means of estimation gives the proportion of blood to that of the body as 1 : 8 or as 1 : 9 (see Prof. Dunglison's "Physiol.," 7th edit., vol. ii. p. 102), and is in accordance

2. *Physical, Chemical, and Structural Characters of the Blood.*

143. The Blood as it flows-forth from an opening in a large vessel, is an apparently homogeneous liquid, possessing a slight degree of viscidity, with a consistence and density somewhat greater than that of water, but especially distinguished by its *colour*, which is usually of a bright scarlet when it is drawn from an artery, and of a dark purple, sometimes almost approaching to black, when it is drawn from a vein. This difference of colour, however, is by no means constant; for arterial blood may sometimes be unusually dark, whilst venous blood is occasionally so florid that it might almost be taken for arterial. The former condition is observable, when from any cause the respiratory process is imperfectly effected, as in the fœtus, and it may be especially noticed during operations performed under the influence of anæsthetic agents; it has also been remarked by Dr. John Davy, as usually characterizing the arterial blood of the inhabitants of hot climates:* but in any of these cases, the ordinary arterial hue is acquired by the blood, when it has been sufficiently exposed to the air. The florid hue is presented by the venous blood of animals which are made to respire pure oxygen; but it seems normal with some individuals whose respiration is peculiarly active. It is well marked in the blood returning from an actively secreting gland, and from a quiescent muscle.† When ordinary venous blood is examined in thin layers, it presents a deep red or purple tint by reflected light, but by transmitted light it assumes a greenish hue, thus presenting the phenomena of Dichroism; a peculiarity which is not possessed by arterial blood (Brücke): but when the gases of the blood are wholly removed by exhaustion, both arterial and venous blood assume a deep black colour.‡—The specific gravity of the Blood is stated by Nasse§ to vary (within the limits of health) between 1050 and 1059; the average being taken at 1055. The spec. gr. of the Corpuscles is about 1088, and that of the fluid in which they float about 1028. The chemical reaction of the blood is invariably alkaline, and very important purposes are served by this alkalinity.—The temperature of the Blood, usually considered to be about 100° F., has been found by Bernard,‖ in an extensive series of observations made with extremely sensitive thermometers, to vary several degrees in different parts of the body. The blood which has the lowest temperature under ordinary circumstances is that which has circulated through the cutaneous capillaries, where it has been exposed to the cooling influences of evaporation and radiation; though Bernard ascertained that on carefully enveloping the head or limbs of an animal in cotton wool, the temperature of the arterial and venous blood soon became equalized. The blood of the left ventricle again is, for similar reasons, uniformly of a lower temperature than that of the right. The highest temperature is attained in passing through

with the results obtained by Lehmann and Weber in their examinations of the quantity of blood discharged from two decapitated criminals (Lehmann, "Lehrbuch," 2nd edit. band ii. p. 234).

* "Anatomical and Physiological Researches," vol. ii. p. 140.—This fact, which harmonizes with the inference to be drawn from the observed results of a high external temperature in reducing the excretion of carbonic acid (Chap. VII., Sect. 2), is of great practical importance.

† Bernard, "Leçons," 1859, vol. i. p. 324.

‡ Setschenow, "Sitzungsberichte d. Kais. Akad. d. Wiss," xxxvi. 1859.

§ Wagner's "Handwörterbuch der Phys.," Art. 'Blut,' band i. p. 82.

‖ "Leçons sur les Liquides de l'Organisme," 1859, iii., iv., v., vi.

glands, muscles, and nerves; for in all such parts, especially during the active performance of their functions, energetic processes of oxydation are being carried on. Hence the blood of the Vena Portæ, which has traversed the capillaries of the intestines, spleen, &c., is warmer, especially during digestion, than even the arterial blood; and that which possesses the highest temperature in the body, and which is frequently 2° or 3° F. above the ordinary venous blood, is that of the Hepatic Vein, which has been subjected to the active assimilative operation of the liver.—When we add that the Blood has a saltish taste, and a faint odour resembling that of the pulmonary and cutaneous exhalations of the animal from which it is drawn, we have enumerated all the characteristics which can be made out by the unassisted senses.

144. When the Blood is examined with the Microscope, however, either immediately upon being drawn, or whilst it is yet circulating in the vessels of the living body (as in the foot of the Frog, the wing of the Bat, or any other membranous expansion of similar transparency), it is seen that its apparent homogeneity is not real, but that it consists of two very different components. These are, a transparent and perfectly colourless liquid which is known as the *Liquor Sanguinis*, and a set of *Corpuscles* which are suspended in it: the great mass of these last present a distinctly *red* hue, and it is to their presence alone that the colour of the blood is due; but there are also to be seen, scattered among the red, a few which are *colourless*, and which differ from the red in some other particulars presently to be noticed.—On the other hand, when the Blood has been drawn from the body, and is allowed to remain at rest, it undergoes a spontaneous coagulation, in the course of which it separates into a red *Crassamentum*, and a nearly colourless *Serum*. The 'crassamentum' or 'clot' is composed of a network of Fibrin, presenting a more or less distinct fibrous texture; in the meshes of which the Corpuscles, both red and colourless, are involved, together with a certain amount of serous fluid. The 'serum,' which is the same with the 'liquor sanguinis' deprived of its fibrin, coagulates by heat, and is therefore known to contain Albumen; and if it be exposed to a high temperature, sufficient to decompose the animal matter, a considerable amount of earthy and alkaline Salts remains.—Thus we have four principal components in the Blood; namely, *Fibrin*, *Albumen*, *Corpuscles*, and *Saline matter*. In the *circulating* blood, they are thus combined:—

Fibrin Albumen Salts	In solution, forming Liquor Sanguinis.
Corpuscles,—suspended in Liquor Sanguinis.	

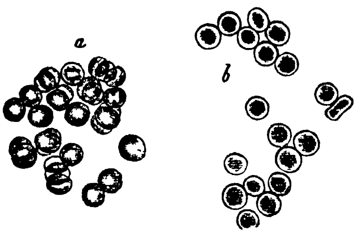
But in *coagulated* blood, they are combined as follows:—

Fibrin Corpuscles	Forming Crassamentum, or Clot.
Albumen Salts	Remaining in solution, forming Serum.

The change from the one condition to the other is due to the fibrillation of the fibrin; which usually takes place so speedily, as to involve the Corpuscles floating in the 'liquor sanguinis,' before they have time to subside; although, under various conditions hereafter to be described, it may occur in such a manner that the clot, or a portion of it, is left colourless.

145. The *Red Corpuscles* of the Blood (commonly, but erroneously, termed 'globules') are minute bodies of a flattened or discoidal form, which, in Man, as in most of the Mammalia, have a distinctly-circular outline (Figs. 36, 37). In the discs of Human blood (37, I), when this is examined in its natural condition, the sides are somewhat concave; and there is a bright spot in the centre, which has been regarded by many as indicating the existence of a nucleus; though it is really nothing else than an effect of refraction, and may be exchanged for a dark one by slightly altering the focus of the Microscope (Fig. 36). The form of the disc is very much altered by various reagents; for, if the Red Corpuscles be treated with water, or with a solution of sugar, albumen, or salt, which is of less density than the liquor sanguinis, they first become flat, and then double-convex, so that the central spot disappears; and by a continuance of the same process, they at last become globular, and so attenuated that a diffusion of their substance seems to take place through the surrounding liquid. If, on the other hand, they are treated with a thick syrup or with a strong solution of albumen or of salt, they assume a shrunken appearance; the first effect of the process being to increase the concavity, and to render the central spot more distinct.[*] It is probable that the Blood-corpuscles, even whilst they are circulating in the living vessels, are liable to alterations of this kind, from variations in the density of the fluid in which they float; and that such alterations may be constantly connected with certain disordered states of the system.[†] Thus, even without such an alteration in the Blood as would constitute disease, its proportion of water may be temporarily so much diminished by diuresis or excessive perspiration, unbalanced by a corresponding ingestion of liquid, that the corpuscles may be made to present a granulated edge; which is rendered smooth again by the dilution of the liquor sanguinis with water. We hence see the necessity, in examining the Blood microscopically, for employing a fluid for its dilution, that shall be as nearly as possible of the same character with its ordinary 'liquor sanguinis.'— In the accompanying Fig. (37), which shows the form and size of the red blood-corpuscles of animals belonging to each division of the Vertebrate class, most accurately drawn to scale by Mr. Gulliver,[‡] it will be seen

FIG. 36.



Red Corpuscles of *Human Blood;* represented at *a*, as they are seen when rather beyond the focus of the microscope; and at *b*, as they appear when within the focus.

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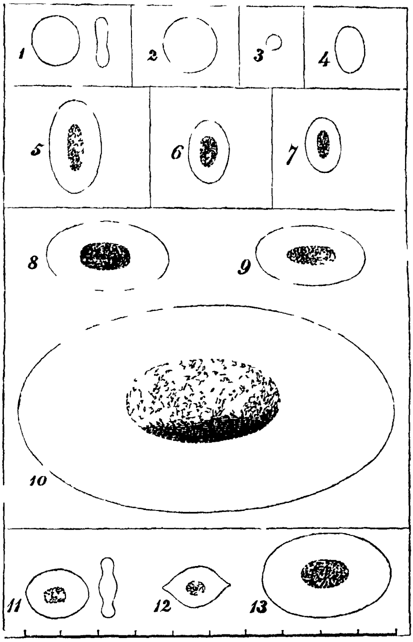
[*] A large number of experiments of this kind were made, and their results accurately recorded, by Hewson (see his "Inquiry into the Properties of the Blood," 1782, and his "Description of the Red Particles of the Blood," 1788), who drew from them the inference of the *vesicular* character of the Red Corpuscles. See also the Lectures of Mr. Ancell on the Blood, in the "Lancet" for 1839; the Memoir of Dr. G. O. Rees and Mr. S. Lane, in "Guy's Hosp. Rep.," No. xiii.; and the excellent Lectures by Mr. Gulliver, delivered at the College of Surgeons in 1862–63, in "Med. Times and Gazette."

[†] See Dr. G. O. Rees's 'Gulstonian Lectures' in the "Medical Gazette" for 1845.

[‡] See 'Proceedings of the Zoolog. Soc. of London," 1862, p. 101.

that whilst in Man and all Mammalia, with the exception of the Camel tribe (4), they are circular, and destitute of a nucleus, or apyrenæmatous,* in Birds, Reptiles, and Fish the corpuscles are uniformly oval and nucleated, or pyrenæmatous: in the Camel tribe, though the corpuscles are oval, yet they conform to the Mammalian type in being free from a nucleus. Mr. Gulliver has particularly insisted on this

Fig. 37.



All the Corpuscles here shown are drawn to a uniform scale of 1-4000th of an inch, and the measurements are expressed in fractions of an English inch. T. D. signifies transverse diameter; L. D. long diameter, S. D. short diameter.

		T D.	L. D.	S. D.
	MAMMALIA.			
1.	Red Corpuscle of Man, seen on the flat surface and also on the edge, thickness 1-12,400	1-3200		
2.	„ „ of Elephant	1-2745		
3.	„ „ of Musk Deer	1-12325		
4.	„ „ of Dromedary, thickness 1-15,337		1-3254	1-5921
	AVES.			
5.	„ „ of Ostrich		1-1649	1-3000
	Nucleus of ditto		1-3200	1-9166
6.	„ „ of Pigeon		1-2314	1-3429
7.	„ „ of Humming Bird		1-2666	1-4000
	REPTILIA.			
8.	„ „ of Crocodile		1-1231	1-2286
9.	„ „ of Python		1-1440	1-2400
10.	„ „ of Proteus		1-1400	1-727
	PISCES.			
11.	„ „ of Perch		1-2461	1-3000
12.	„ „ of Pike		1-2000	1-3555
13.	„ „ of Shark		1-1143	1-1684

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* *α*, not, *πυρην*, a nucleus, and *αιμά*, blood.

difference in the blood of the Mammalian and Oviparous Vertebrata, maintaining it to be the only single, universal, and characteristic difference between them.[*]—In the present state of our knowledge it is difficult to say whether the Red Blood-corpuscles of Man and Mammalia are to be regarded as cells or as nuclei. In the majority of modern physiological works they are described as cells, possessing cell-wall and contents; and from the peculiar reactions which they present with solution of magenta and of tannin, Dr. Roberts, of Manchester, has been led to conceive that they actually possess a double wall, an external one corresponding to the outer or secondary cell-wall of plants, and an inner more delicate one corresponding to the primordial utricle[†] On the contrary, Dr. Dalton,[‡] from a study of their microscopical characters, regards them as being minute but perfectly homogeneous masses of organized substance, of the same colour, consistency, and composition throughout; whilst Mr. Gulliver and Mr. Wharton Jones, from considerations connected with their development, regard them as free nuclei, though modified in such a manner as to possess quite special characteristics.

146. The *form* of the Red Corpuscles is not unfrequently seen to change during their circulation; but this is generally in consequence of pressure, from the effects of which, however, they quickly recover themselves. In the capillary vessels, they sometimes become suddenly elongated, twisted, or bent, through a narrowing of the channel; and this change may take place to such a degree as to enable the disc to pass through an aperture which appears very minute in proportion to its diameter. When undergoing spontaneous decomposition, the blood-discs become granulated, and sometimes (as long since noticed by Hewson) even mulberry-shaped; and particles in which these changes appear to be commencing, may be found in the blood at all times—The *size* of the blood-discs is liable to considerable variation, even in the same individual, some being met-with as much as one-third larger, whilst others are one-third smaller, than the average The diameter of the corpuscles bears no constant relation to the size of the animal, even within the limits of the same Class; thus, although those of the Elephant (2, Fig 37) are the largest among Mammalia (as far as is hitherto known), those of the Mouse tribe are far from being the smallest, being, in fact, more than three times the diameter of those of the Musk Deer (3, Fig 37). There is, however, as Mr. Gulliver has remarked, a more uniform relation between the size of the animal and that of its blood-discs, when the comparison is made

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[*] The following measurements of the blood of domestic animals expressed in fractions of an English inch) may be selected from Mr Gulliver's very numerous and accurate measurements, as the most likely to become of interest in Juridical inquiries, though it must be remembered that the corpuscles shrink slightly in the process of drying.

Man	1-3200	Mouse .	1-4230	Cat	1-4404
Dog .	1-3532	Ass .	1-4267	Horse . . .	1-4600
Hare	1-3560	Pig . .	1-4230	Sheep . . .	1-5300
Rabbit	1-3607	Ox . .	1-4267	Goat . . .	1-6366
Rat .	1-3754	Red Deer	1-4324		

A Tabular summary of Mr. Gulliver's very numerous and accurate measurements of the Red Corpuscles of the Blood of different animals, from all the classes and most of the orders of the Vertebrate series, is contained in the "Proceedings of the Zoological Society," No. cii , and also in his Edition of the "Works of Hewson" already referred to, published by the Sydenham Society (p 237).

[†] See "Proceed of Royal Society," vol xii 1863, p 481

[‡] See his "Human Physiology," 1859, p 181.

within the limits of the same Order. In Man, their diameter varies from about 1-4000th to 1-2800th of an inch, the average diameter being probably about 1-3200th; and their average thickness, according to the same excellent observer, is about 1-12,400th of an inch. According to the recent estimates of Vierordt, a cubic centimetre of blood (which is no more than about 6-100ths of a cubic inch) contains no fewer than 5,055,000 red corpuscles, and about 14,000 colourless ones: whilst by Welcker the number in the same quantity is estimated at 4,600,000.*—The *colour* of the Red Corpuscles is very pale when they are lying in a single stratum; and it is only when we see three or four superposed one upon another, that the full deep red tint of their contents becomes apparent. The cause of the difference in hue between the corpuscles of arterial and those of venous blood, will be considered hereafter.

147. The Red Corpuscles are composed of a substance termed Hæmatoglobulin, which under favourable conditions is capable of assuming a crystalline form. This circumstance has led many to consider it a definite chemical compound of homogeneous and uniform composition, whilst others regard it as composed of two materials,—Globulin, a coagulable substance nearly allied to Albumen, and Hæmatin, to which the colour of the corpuscles is altogether due; and recently C. G. Lehmann† has stated that he has been able to separate the hæmatin from the albuminous constituent, which he terms Hæmatocrystallin, and has obtained the latter in colourless crystals. The difficulty of determining this question is greatly increased from the variety of substances which have been termed Hæmatin by chemists, and also from the circumstance that several kinds of crystals have been obtained from blood. According to v. Gorup-Besanez,‡ we are still unacquainted with the true colouring matter of the blood; for whilst the Hæmatin of Lecanu and of Berzelius is amorphous and insoluble in water, alcohol, ether, and oils, that of Sanson and that obtained by Robin and Verdeil, though amorphous, is soluble in alcohol, ether, and dilute acids; whilst that obtained by Lehmann as the result of the action of a mixture of 1 part of alcohol, 4 parts of ether, and 1-16th of oxalic acid upon fresh blood is crystalline, presenting the form of thin brownish and brownish-green striated transparent laminæ, often curiously twisted upon their long axis, and soon spontaneously changing into flat rhombic octohedra. The Globulin, if it be really a distinct substance, certainly stands in close relation to albumen, and constitutes by far the largest portion of the corpuscles. Its solutions coagulate on heating, but do not perfectly separate; the fluid passing through a filter in a turbid condition. The original solution in water has a neutral reaction; but after coagulation and filtration the fluid gives an acid reaction, probably from the presence of acid phosphates. When a solution of globulin is made either with dilute acetic acid or dilute ammonia, precipitation occurs on exactly neutralizing the fluid.

148. As regards the Crystals which can be obtained from the Blood, Bojanowski§ has enumerated no less than four varieties, which are respectively termed Hæmatoglobulin, Hæmatoidin, Hæmatin, and Hæmin.

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* See Prof. Lehmann's "Physiologischen Chemie," 2nd edit., band ii. p. 194.

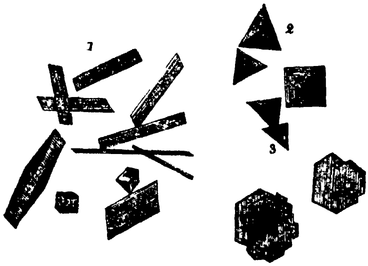
† Henle and Meissner's "Bericht," 1859, p. 255.

‡ "Phys. Chemie," 1862, p. 168.

§ See Siebold and Kölliker's "Zeitschrift," band xii. 1862, p. 312.

I. Hæmatoglobulin Crystals (Funke) may be obtained from blood through which first oxygen and then carbonic acid has been conducted under the influence of sunlight; or it may be found in blood that has simply stood in a cold temperature for some hours. They present considerable variety of form in different animals. In Man, from whose splenic blood they can be obtained with facility, their shape is sometimes that of elongated rectangular prisms, and sometimes that of rhombs; in the Mouse and Guinea Pig they form tetraedra, in the Hamster rhombohedra, whilst in the Squirrel they are hexagonal.* They are unstable, deliquescing on exposure to the air, and soluble in water, the solution giving a precipitate on being heated. Acetic acid and ammonia dissolve them readily, but they are insoluble in alcohol. They are doubly refractile and pleochromatic as regards light, and appear to be destitute of taste and smell.

FIG. 38.



Blood-Crystals, (1) prismatic, from Human blood, (2) tetraedral, from Pig's blood, (3) hexagonal plates, from Squirrel's blood.

II. It is uncertain whether the crystals which form in blood that has long been extravasated, as in old apoplectic clots and corpora lutea, consist of Hæmatoglobulin or of Hæmatin alone, though the probability is in favour of the latter. They are termed Hæmatoidin crystals by Virchow, form rhombic plates, and appear to be of a more stable character than those last mentioned. They are insoluble in water, alcohol, ether, and acetic acid, but are soluble in chloroform, and give with sulphuric acid a play of colours similar to those given by Bile with nitric acid; which is a fact of importance when connected with Zenker and Funke's observation, that Bilifulvine can readily be converted into Hæmatoidin.

III. The Hæmatin Crystals obtained by Foller and others, by the continuous transmission of Carbonic Acid through a solution of Hæmatin, appear to resemble the preceding Hæmatoidin Crystals very closely in their reactions. Bojanowski was, however, unable to obtain them.

IV. Lastly, the exact nature of the Hæmin Crystals, which Teichmann obtained by the action of strong Acetic Acid on Blood and evaporation at a low temperature, is still undetermined. Their colour is red brown or black, becoming violet on exposure to oxygen, and losing their transparency on exposure to carbonic acid; their form is that of rhombic tablets, often arranged in stars or crosses; and they are insoluble in most reagents. The formation of these crystals has been employed as a test for stains of blood in medico-legal investigations.†

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* These several varieties may, however, according to Dr. Rollett ("Moleschott's Untersuch." 1863, p. 22), be reduced to two systems of crystalline forms, namely, the Rhombic and the Hexagonal, to the latter of which the crystals of the blood of the Squirrel alone belong; those of the Guinea Pig, hitherto considered as regular crystals, being in reality the halves of Rhombic pyramids.

† See Teichmann, "Zeitschrift f. Rat. Med.," N. F. iii. 375, viii. 141; Kölliker,

149. The following is given by Prof. Lehmann* as the relative Chemical constitution of the Red Corpuscles and of the Liquor Sanguinis, which there is a great advantage in thus bringing into comparison :—

1000 parts of *Red Corpuscles* contain		1000 parts of *Liquor Sanguinis* contain	
Water	688·00	Water	902·90
Solid residue	312·00	Solid residue	97·10
Hæmatin (including iron)	16·75	Fibrin	4·05
Globulin and cell-membrane	282·22	Albumen	78·84
Fat	2·31	Fat	1·72
Extractive matters	2·60	Extractive matters	3·94
Mineral substances (inclusive of iron)	8·12	Mineral substances	8·55
Chlorine	1·686	Chlorine	3·644
Sulphuric Acid	0·066	Sulphuric Acid	0·115
Phosphoric Acid	1·134	Phosphoric Acid	0·191
Potassium	3·328	Potassium	0·323
Sodium	1·052	Sodium	3·341
Oxygen	0·667	Oxygen	0·403
Phosphate of Lime	0·114	Phosphate of Lime	0·311
Phosphate of Magnesia	0.073	Phosphate of Magnesia	0·222

From this we see that not only do the Hæmatin and Globulin of the Corpuscles replace the Fibrin and Albumen of the Liquor Sanguinis, but the proportion of Fat in the former is considerably greater than in the latter ; and that although the whole amount of mineral matter (excluding the iron of Hæmatin, which would amount to 1·17) is nearly the same in the Corpuscles as in the Liquor Sanguinis, yet that there is a most remarkable and significant difference in its constituents in the two cases respectively. For while the Chlorine of the corpuscles is to that of the liq. sang. as 1 : 2·16, the Phosphoric acid of the corpuscles is to that of the liq. sang. as nearly 6 : 1 ; and whilst the Sodium of the corpuscles is to that of the liq. sang. as 1 : 3·3, the Potassium of the corpuscles is to that of the liq. sang. as 10·3 to 1. Hence it is obvious that the Chloride of Sodium of the blood must be principally, if not (as Sacharjin contends) entirely contained within the liquor sanguinis, whilst the Potash of the blood is almost wholly included in the substance of the corpuscles; and from the excess of Phosphorus in the corpuscles, as well as of Fat, it may

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"Manual of Human Histology," 1860 ; Virchow, "Cellular Pathology," 1860, pp. 143-145 ; v. Gorup-Besanez, "Phys. Chem.," 1862, pp. 170-194 ; Funke, "Physiologie," 4th edit. 1863, p. 45.

[*] "Physiological Chemistry" (translated by Dr. Day), vol. ii. p. 160.—It is to the admirable Essay of Schmidt, "Charakteristik der Cholera," that Physiologists and Chemists are indebted, for the first direction of their attention to the importance of separately estimating the composition of these two principal constituents of the Blood, and for the indication of the means of doing so. Recent investigations by Sacharjin have thrown some doubt upon Schmidt's calculations, on which the above table is founded, and which were made on the assumption that the proportion of moist corpuscles could be ascertained by multiplying the weight of dry corpuscles (obtained by the method of Prevost and Dumas) by 4. The following table shows the difference in the results obtained by the two experimenters :—

In 1000 parts of Blood.	*Schmidt.*	*Sacharjin.*
Moist Corpuscles	513·04	344·177
Liquor Sanguinis	486·96	655·823
	1000	1000

It is requisite to observe, however, that Sacharjin's experiments were made on the blood of the Horse. See "Canstatt's Bericht," 1861, p. 213.

be fairly concluded, that it is in them that the peculiar 'phosphorized fats' are chiefly formed. The Red Corpuscles appear to have a remarkable power of absorbing certain gases; for it has been found by Van Maack and Scherer, that a solution of hæmatin imbibes a considerable amount of oxygen, the latter of these chemists having also ascertained that after the absorption of oxygen there is a slight development of carbonic acid. The Red Corpuscles are considerably heavier than the serum in which they are suspended; their normal specific gravity being from 1088·5 to 1088·9 in man, and from 1088·0 to 1088·6 in woman; while that of the Serum averages 1028.

150. In addition to what has been already stated of the influence of water, saline and other solutions, and acetic acid, upon the form and condition of the Red Corpuscles, the following facts may be stated with regard to the effects of these and other reagents. Upon exposure of the corpuscles to the influence of pure water, they swell up, become globular, and so pale that their outline can only be traced with the greatest difficulty. Yet unless putrefaction have set in, it is certain that they are not soluble in it, since they can readily be again brought into view, even after weeks of maceration, by the application of a little iodine or corrosive sublimate.* The numerous observations made upon the action of various reagents upon the corpuscles by Muller, Humfeld, Simon, and others, are almost useless, from the circumstance that they were made indifferently on the blood of frogs and on that of the higher Vertebrata, although the effects produced in the two cases are very different. As a general rule, it may be stated that the red corpuscles of Man and the higher Mammalia resist chemical reagents (like nuclei in general) to a very extraordinary degree, whilst the pale corpuscles are more easily acted on, becoming ropy (like fresh cells in general) under the influence of alkalies and various alkaline salts. Bile and urea appear, however, to dissolve the red blood-cells; though the addition of Urine seems to exert no other influence upon them than a saline solution of equal density would do, as was long since ascertained by Hewson. With solutions of magenta they swell up and assume a faint rose colour, whilst a dark red spot appears upon some point of their circumference. The white corpuscles are stained of a deeper red, and their nuclei, which are brought clearly into view, become of a deep carbuncular red colour. With solutions of tannin, after the lapse of twenty or thirty seconds, some point of the circumference of the red corpuscle appears to give way, and a small button of a highly refractile substance projects, which sometimes appears to contain a vesicular body, that can again be retracted into the corpuscle by the action of acetic acid.† It is further remarked by Prof. Lehmann, that some of the Red Corpuscles resist the influence of reagents much more than others do; and he infers that the latter are the older cells, as having the strongest tendency to disintegration; whilst those which present an unusual resisting power, he infers to be young cells which have not yet acquired the normal characters of the red corpuscles.‡

151. The Red Corpuscles, when freely floating in the liquor sanguinis

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* Gulliver, "Lond. and Edin. Phil. Mag." for 1840, p. 106; and Lecture i., "Med. Times," 1862, p. 102.

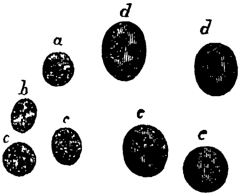
† Roberts, *loc. cit.* See also Rindfleisch, "Experimental Studien über die Histologie des Blutes," Leipzig, 1863.

‡ Op. cit., vol. ii. pp. 184, 185.

of blood no longer in motion, exhibit a marked tendency to approximate one another; usually coming into contact by their flattened surfaces, so that a number of them thus aggregated present the appearance of a pile of coins; or, if the stratum be too thin to permit them to lie in this manner, partially overlapping one another, or even adhering by their edges, which then frequently become polygonal instead of circular. The corpuscles when thus adherent, resist the influence of forces which tend to detach them, and will even undergo considerable changes of shape, rather than separate from each other; if forced asunder, however, they resume their normal form. After thus remaining adherent for a time, they seem to lose their attractive force; for they are then seen to separate from each other spontaneously. This peculiar tendency to aggregation is most strongly manifested in inflammatory blood, and assists in the production of the buffy coat; whilst, on the other hand, it seems to be neutralized by the action of most saline substances, since, if these be added to the blood, the corpuscles do not run together, or instantly separate if they have already become adherent.

152. Besides the red corpuscles of the Blood, there are others which possess no colour, and might seem to have a function altogether different; these are known as the *White* or *Colourless* corpuscles. Their existence has long been recognized in the blood of the lower Vertebrata, where, from being much smaller than the red corpuscles, as well as from differing widely in shape, they could readily be distinguished. But it is only of late (chiefly through the researches of Gulliver,* Addison,† and others), that they have been recognized in the blood of Man and other Mammalia; their size being nearly the same with that of the red corpuscles; and the general appearance of the two (owing to the circular form of the latter, and the absence of a central nucleus,) being less diverse (Fig. 39). It is remarkable that, notwithstanding the great variations in the size of the *red* corpuscles in the different classes of Vertebrata, the dimensions of the *colourless* corpuscles vary but little throughout the Vertebrate subkingdom; their diameter being seldom much greater or less than 1-3000th of an inch in the warm-blooded Vertebrata, and 1-2500th of an inch in Reptiles. This holds good even in those animals,—such as the Musk-Deer, and the Proteus,—which present the widest departure from the general standard in the size of their red corpuscles; so that the colourless corpuscle is as much as four times the diameter of the red, in one instance; whilst it is not one-eighth of the long diameter of the red, in the other.—The common pale Corpuscles of the Blood, though similar in appearance, are somewhat larger than the proper globules of lymph or chyle, and there is a marked difference in their

FIG. 39.



Colourless Blood-corpuscles, or Lymph-corpuscles of the Blood :—*a*, *b*, small cells, such as are found in the Thoracic duct, seen on their flat side at *a*, and edgewise at *b*; *c*, *c*, the same, with obvious nuclei; *d*, *d*, larger cells, with originally-multiple nuclei; *e*, *e*, the same, treated with acetic acid, showing the breaking-up of the nuclei.

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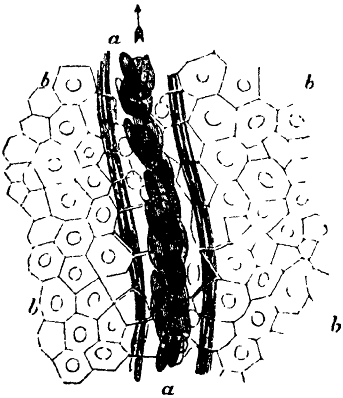
* Notes and Appendix to Translation of "Gerber's General Anatomy."

† "Transactions of Provincial Medical Association," 1842 and 1843.

chemical properties. In Mammalia and Birds the lymph-globule is a nucleus, while the common pale corpuscle of the blood is a cell containing a nucleus. The lymph-globule or nucleus is only slightly acted on by acetic acid, but the pale cell energetically, its nucleus immediately becoming apparent even when very dilute acid is employed. The nucleus of the white corpuscle is not, however, identical with the lymph-globule, since it divides into two or three smaller bodies on the addition of strong acetic acid, which is not the case with the lymph-globule. In fibrous clots a third kind of pale corpuscle has been observed by Mr. Gulliver,* which is characterized by its small size, faint outline, and resistance to the action of acetic acid. The Colourless corpuscles possess a higher refracting power than the red; from which they are further distinguished by their greater firmness, their want of elasticity, and the absence of any disposition to adhere to each other; so that, when a drop of recent blood is placed between two strips of glass, and these are gently moved over one another, the white corpuscles may be at once recognized by their solitariness, in the midst of the rows and irregular masses formed by the aggregation of the red. This is still better seen in inflammatory blood; in which the Red corpuscles have a peculiar tendency to adhere to one another, so that the distinctness of the White is more marked (Fig. 43).

FIG. 40.



A small Venous trunk, *a*, from the Web of the *Frog's* foot; *b*, *b*, cells of pavement-epithelium, containing nuclei. In the space between the current of oval Blood-corpuscles, and the walls of the vessel, the round transparent colourless corpuscles are seen.

153. Colourless corpuscles may be readily distinguished in the blood circulating through the small vessels of the Frog's foot; and it is then observable that they occupy the exterior of the current, where the motion of the fluid is slow, whilst the *red* corpuscles move rapidly through the centre of the tube (Fig. 40). The Colourless corpuscles, indeed, often show a disposition to adhere to the walls of the vessels; which is manifestly increased on the application of an irritant. Hence the idea naturally arises, that (to use the words of Mr. Wharton Jones) "there is some reciprocal relation between the colourless corpuscles, and the parts outside the vessels, in the process of nutrition."—A very remarkable spontaneous change of form has been observed by Mr. Wharton Jones to take place in the Colourless corpuscles whilst being examined under the microscope;† and this not only in the blood of Man, but in that of animals of all the Vertebrated classes, as also in that of Invertebrata, whose only corpuscles are of this character. From some point of their circumference, a protrusion of the cell-wall takes place, the form of which seems quite indefinite; soon afterwards, another protrusion

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* "Med. Times and Gaz.," vol. i. 1863, p. 207.

† "Philosophical Transactions," 1846, pp. 64, 71, 90, &c.

may be seen to arise from another part of the cell, the first being either drawn-in again, or remaining as it was; and thus the configuration of the corpuscles may be seen to undergo several changes before the process finally ceases, and this whilst they are floating in their own serum, and the red corpuscles are lying quite passive in their immediate vicinity. These changes of form (which bear a striking resemblance to those of the *Amœba*) are affirmed by Dr. Davaine* to be visible even whilst the blood is circulating through the vessels, in those colourless corpuscles which are retarded by attraction to their walls.

154. The proportion which the White or Colourless corpuscles bear to the Red, is very small in the blood of Man and the higher Vertebrata; being, in the state of health, according to the estimate of Moleschott (which is confirmed by Kolliker†), not more than 2·55 to 1000. It varies, however, to a very remarkable extent, as has recently been shown by Dr. Hirt, of Zittau,‡ according to whether the examination be made before or after food. Thus in the morning before breakfast the proportions were one colourless to 716 coloured corpuscles; half an hour after breakfast 1:347; between two and three hours after breakfast 1:1514; ten minutes after dinner 1:1592; half an hour after dinner 1:429; two hours and a half to four hours after dinner 1:1481; half an hour after supper 1:544; and between two and a half to three and a half hours after supper 1:1227. Similar results have also been obtained by Marfels and Lorange.§ The white corpuscles are very numerous in the Splenic Venous Blood: (Gray, Virchow). They are more abundant in children than in adults, and there is an increase during pregnancy and in certain diseased conditions of the system. In the oviparous Vertebrata, the proportion is higher; thus it has been observed by Wagner‖ to be as 1:16 in the blood of a Frog examined in February, and as 1:6 in similar blood examined in August. In one Vertebrated animal, the *Amphioxus*, the Red corpuscles are wanting altogether; their place in the circulating blood being taken by the Colourless. And in the Invertebrate series generally, the corpuscles of the circulating fluid correspond rather to the *colourless* corpuscles of the Blood of Vertebrata, and to the corpuscles of Lymph and Chyle (which may be regarded as the same bodies in an earlier stage of development), than they do to the *red* corpuscles, which are peculiar to Vertebrata.¶ Thus, in one of its most characteristic features, the Blood of Invertebrata (and of Amphioxus) may be likened rather to the Lymph and Chyle of Vertebrated animals, than to their Blood; and this resemblance is strengthened by the fact, that there is no distinction in the former between the *absorbent* and the *sanguiferous* vessels, which in the latter respectively contain the nutritious fluid in its earlier and in its later stages of development. Moreover, the earliest blood-corpuscles of the embryo of even the highest Vertebrata are colourless; and long after the blood has acquired its characteristic hue

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[*] "Mémoires de la Société de Biologie," tom. ii. pp. 103-5.

[†] "Manual of Human Histology" (Sydenham Society's edition), vol. ii. p. 330.

[‡] "Müller's Archiv," 1856, p. 174.

[§] Ludwig, vol. ii. p. 38, 1861.

[‖] "Elements of Physiology," translated by Dr. Willis, p. 246.

[¶] See Mr. Wharton Jones's Memoir on 'The Blood-Corpuscle considered in its different Phases of Development in the Animal Series,' in the "Philos. Trans.," 1846; also "Princ. of Comp. Phys.," 4th ed. §§ 379-382.

from the development of red corpuscles, the colourless corpuscles bear a very large proportion to the red, so as even to equal them in number (as the author is informed by Mr. Gulliver) in the blood of fœtal Deer an inch and a half long, and absolutely to preponderate in the blood of still smaller embryoes.

155. There can be no doubt that both the Red and the Colourless corpuscles have, like other Cells, a definite term of life; and that, whilst some are undergoing disintegration, others are in a state of advancing development to supply their places, so that the entire mass of both is undergoing continual change. That a new production of Red corpuscles may take place with considerable rapidity, we have evidence in the rapid restoration of their normal proportion after it has been lowered by hæmorrhage (§ 166), and in the speedy increase which may be effected in their amount in blood in which they have been excessively diminished by disease (§ 179); this being especially promoted by the administration of Iron, and by a generous diet. On the other hand, various appearances indicative of degeneration may be seen in the Red corpuscles; and this especially in the blood of the Oviparous Vertebrata, which usually contains corpuscles almost destitute of colour, and having a shrunken or eroded aspect, their nuclei, however, presenting a remarkable distinctness. That, under certain circumstances, such a degenerating process takes place with great rapidity in the blood which circulates through the Spleen, may be considered as ascertained almost beyond a doubt (§ 130, III.). Of the ordinary duration, however, of the life of either the Red or the Colourless corpuscles, we have not at present any means of making an approximative estimate.—The question now arises, in what manner the two classes of Corpuscles are respectively developed, and whether they have any relationship to each other.

156. That the fully-developed Red corpuscles, when ceasing to exist as such, do *not* give origin to new corpuscles of the same kind, may now be asserted (notwithstanding the statements of former observers) to be the concurrent opinion of nearly all who have in recent times specially devoted themselves to this inquiry. The *first* Red corpuscles unquestionably have their origin, like the original cells of the solid tissues, in the primordial cells of the germinal structure; and it is in the so-called 'vascular layer' of the 'blastodermic vesicle' (CHAP. XVI. Sect. 4), and in the mass of cells which constitutes the rudiment of the heart, that this metamorphosis seems first to take place. The situation of the heart, and the course of the principal trunks of the 'vascular area,' are early marked-out, by the peculiar disposition of the aggregations of cells from which these organs are to be developed; and whilst the *outer* portions of these aggregations are transformed into the *walls* of the respective cavities, the *inner* portions seem partly to deliquesce, and partly to remain as isolated cells floating in the liquid thus produced. These isolated cells are the first blood-corpuscles; and the following account of them in the Oviparous Vertebrata or Pyrenœmata is given by Mr. Paget,* who has made them the subject of careful study. "As described by Vogt, Kölliker, and Cramer, they are large colourless vesicular spherical cells, full

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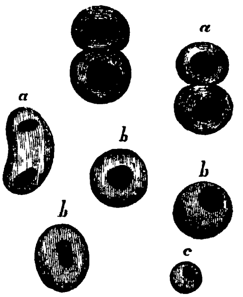
* This account is cited from Messrs. Kirkes and Paget's "Handbook of Physiology," 5th edit. (pp. 69-75), in which it appears as an abstract of a part of Mr. Paget's Lectures on the 'Life of the Blood,' delivered at the College of Surgeons in 1848.

of yellowish particles of a substance like fatty matter; many of which particles are quadrangular and flattened, and have been called stearine-plates, though they are not proved to consist of that or any other unmixed fatty substance. Among these particles each cell has a central nucleus, which, however, is at first much obscured by them. The development of these embryo-cells into the complete form of the corpuscles is effected by the gradual clearing-up, as if by division and liquefaction, of the contained particles, the acquirement of blood-colour and of the elliptical form, the flattening of the cell, and the more prominent appearance of the nucleus." The process appears to be essentially the same in the Fish, the Reptile, and the Bird; but it takes place too rapidly in the latter class for its stages to be clearly distinguished; whilst in the tadpole the changes occur so slowly that they can be traced in the blood even while it circulates.—The history of the development of the first red corpuscles in Mammalia is nearly the same; but a binary multiplication of these bodies by subdivision (Fig. 41) has been observed in them by Prof. Kolliker* and others, which has not been noticed elsewhere. In watching the stages of this process, it is seen that the partition of the nucleus takes place completely, before that of the cell itself has commenced. The blood-corpuscles of the Human embryo thus formed, are described by Mr. Paget as "circular, thickly disc-shaped, full-coloured, and, on an average, about 1-2500th of an inch in diameter; their nuclei, which are about 1-5000th of an inch in diameter, are central, circular, very little prominent on the surfaces of the cell, and apparently slightly granular or tuberculated. In a few instances, cells are found with two nuclei; and such cells are usually large and elliptical, with one of the nuclei near each end of the long axis." According to Mr. Gulliver,† these large nucleated, embryonic, red corpuscles in Man and the higher Mammalia must be regarded as the true analogues of the ordinary nucleated red corpuscles of mature oviparous Vertebrata. It is particularly worthy of remark, also, that in the very earliest period pale nuclei destitute of an envelope, but containing nucleoli, are very abundant, giving that whitish hue to the blood which was long ago observed by Glisson and Needham (1667); these appear to be analogous to the pale globules of the blood of adult Vertebrata; and to the characteristic corpuscles of the blood of many Invertebrata; "so that in its course towards the highest type, there are temporary phases in which the blood of the Mammal is analogous to the permanent states of the blood of Invertebrate and of Oviparous

FIG. 41.



Blood-corpuscles of *Fœtal Lamb*—*a*, *a*, bi- and tri-nucleated large colourless elongated blood-cells, in different stages of subdivision, *b*, *b*, spherical blood-cells, one of them having a nucleus beginning to divide, *c*, a smaller cell of the same kind.

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[*] See his Memoir, 'Ueber die Blutkorperchen eines menschlichen Embryo,' &c., in "Zeitschrift fur Ration. Med.," 1846; and his "Manual of Human Histology" (Sydenham Society's edition), p. 342.

[†] Lecture i., "Medical Times and Gazette," vol. ii. 1862, p. 103.

animals respectively."—When the Liver begins to be formed, this multiplication of blood-cells in the entire mass of the blood ceases, and in a short time all trace of the development of the red out of the original colourless formative cells is lost; whilst, on the other hand, there takes place in the vessels of the liver a new production of colourless nucleated cells, which are formed around free nuclei, and which undergo a gradual change (by the development of colouring-matter in their interior) into red nucleated cells resembling those of the first brood. According to Kölliker,* this new formation of blood-corpuscles in the liver continues to take place during the whole of the fœtal life of Mammalia, as in Birds during incubation. Whether these nucleated cells themselves undergo a transformation into the non-nucleated discs characteristic of Mammalia, which constitute a gradually-increasing proportion of the corpuscular components of the blood during the latter period of embryonic life, or whether these are formed only by the metamorphosis of lymph-corpuscles, has not yet been ascertained.

157. That after the Chyle and Lymph have begun to flow into the circulating current, the *continued* generation of Red corpuscles is due to the progressive metamorphosis of the corpuscles of those fluids, is an opinion which has come of late to be very generally received amongst Physiologists; it may be found, however, to require some modification. It rests upon facts of three different orders:—1st, the presence, in the blood of oviparous Vertebrata, of corpuscles exhibiting what appear to be intermediate gradations of development between Lymph-corpuscles and their nucleated Red corpuscles; and this especially in blood in which an unusually rapid development of red corpuscles is taking place, to make up for previous loss; 2nd, frequent ruddiness in the hue of the fluid of the Thoracic duct, which seems to depend upon the incipient development of Hæmatin in some of its floating corpuscles; and 3rd, the progressive transition from one form to the other, which may be observed in the ascending scale of animal existence. To these considerations may be added, the absence of any other mode of production that can be suggested; since the idea of the self-multiplication of the Red corpuscles is almost certainly erroneous, and no special organ can be assigned as the seat of their generation. As to the mode in which the non-nucleated Red corpuscles of Mammalian blood are produced from the Colourless or Lymph-corpuscles, there are two very dissimilar opinions; the *entire* lymph-corpuscle being thus metamorphosed into the red, in the opinion of some; whilst its *nucleus* alone, set-free by the dissolution of the surrounding cell, becomes, in the opinion of others, the ultimate red corpuscle. Mr. Wharton Jones has adduced very cogent evidence, derived chiefly from a comparison of the sizes of the true red corpuscles of different Mammals with those of the nuclei of the white or nucleated corpuscles which their blood contains, that the former are the equivalents of the latter, in a state of higher development; having acquired a vesicular character, and having their interior occupied by globulin and hæmatin. This view, which is also held by Mr. Gulliver, certainly harmonizes well with the fact, which can scarcely be explained on the preceding hypothesis, that the red corpuscles of most Mammalia are *smaller*

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* Op. cit., p. 343.

(often very much so) than the nucleated cells in which they originate.* Mr Gulliver's observations and arguments upon this point appear to be conclusive † He maintains that between the red corpuscles of the adult Mammalian and those of the oviparous Vertebrate animal a marked distinction exists in regard to their mode of development, the former proceeding from the nuclei alone of the pale corpuscles, whilst the latter are developed from the entire white cells, the nucleus permanently remaining, and the envelope assuming the flat shape and red colour Thus this difference in the mode of development would appear as remarkable as the difference in the perfect structure, already described, of the red corpuscles of these two main divisions of Vertebrata ‡ And thus also the Chyle and Lymph seem to be continually supplying, not merely the *pabulum* for organization derived from the food, whereby the components of the liquid part of the blood are replenished as fast as they are withdrawn, but also the rudimentary *corpuscles* which are to be progressively metamorphosed into the coloured discs that float in its current

158 *Composition of the Blood*—The morphological or formed elements of the Blood having been thus separately described, we have now to inquire into the chemical characters of the various components which are associated in the liquid as a whole, and the proportions in which they severally present themselves These are subject, even within the limits of health, to considerable variations, some of which seem to depend upon the constitution of the individual, his diet, mode of life, &c ; whilst others are probably referable to the period at which the last meal was taken, and the amount of bodily exertion made within a short time previous to the analysis Hence no single analysis could represent the average composition of the blood, even if it were itself chemically accurate, but there are difficulties in the way of quantitatively determining with precision the several components of the blood, which interpose a new source of uncertainty and error Notwithstanding the numerous investigations which have been made upon the Blood, the means of separating the several constituents are not sufficiently exact to enable us to arrive at more than an approximative estimate of their respective proportions The marked discrepancy observable between the results obtained by different analysts, especially in regard to the relative proportions of Albumen and Corpuscles, arises in great degree from *the difference of the methods of analysis employed*, as has been proved by M Gorup-Besanez § For he found that when four samples of *the same* blood were examined by the methods adopted by four different experimenters respectively, the results were as follows The first specimen was the blood of a vigorous man fifty years old

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* See "Philosophical Transactions," 1846, pp 75 79 —Mr Wharton Jones's views on this point have been adopted by Messrs Busk and Huxley, see their translation of Prof Kolliker's "Human Histology" (Sydenham Society's edition), vol ii p 347, *note*, and "Quart Journ of Microsc Science," vol i p 145

† See Lectures, "Medical Times and Gazette," 1862

‡ Yet Dr Bennett ("Lancet," vol i 1863, p 378) states that numerous observations have satisfied him that chyle corpuscles may be seen to form, and to be transformed into bodies in every respect, except colour, resembling the biconcave discs of blood, without the intervention of cells

§ "Journ fur Prakt Chem," Band i p 346

	Scherer.	Becquerel and Rodier.	Höfle.	Gorup-Besanez.
Water	796·93	796·93	796·93	796·93
Solid matters	203·07	203·07	203·07	203·07
Fibrin	1·95	1·95	1·95	1·95
Corpuscles	115·16	117·82	103·23	103·23
Albumen	58·82	63·87	50·84	70·75
Extractive matters and salts	27·14	19·43	47·05	27·14

The second specimen was from a robust man twenty years old :—

	Scherer.	Becquerel and Rodier.	Hofle.	Gorup-Besanez.
Water	783·63	783·63	783·63	783·63
Solid matters	216·37	216·37	216·37	216·37
Fibrin	1·56	1·56	1·56	1·56
Corpuscles	113·54	131·52	115·12	115·12
Albumen	64·32	65·91	51·76	62·74
Extractive matters and salts	36·95	17·38	47·93	36·95

159. We have now to notice those less prominent components of the Blood which have not been hitherto described in detail. Under the general head of *Fatty Matters* are included several different kinds of fat, some of which present very definite characters, whilst the nature of others has not yet been precisely determined. A considerable part of the whole amount is formed by the *saponifiable* fats, which, in the Human subject, are Margarin and Olein; and it must be in these that the chief increase occurs, when the amount of fatty matter in the blood is temporarily augmented by the entrance of oleaginous chyle (§ 165). The proportion of *phosphorized* fat, which seems to form an essential constituent of the Corpuscles (§ 149), will probably vary in part with their amount; but the range of variation seems to be too wide to admit of the difference being fully accounted-for in this manner. The presence of *Cholesterin* seems to be constant; but it, too, exhibits a considerable diversity in its amount, probably depending upon the relations between the biliary secretion and the respiratory process. Of the fatty substance termed *Serolin*, the quantity is always very minute, and it is sometimes inappreciable. The kind of food materially affects the quantity of fat contained in the blood. Nasse found 2·6 parts of fat in 1000 of the blood of a dog that had been kept fasting for 4 days. After bread diet it rose to 3·1 parts, after meat to 3·8, and after suet and starch to 4·1 parts in 1000.—The following table represents the mean, maximum, and minimum amounts of these fatty substances in the healthy blood of Man (the proportion in that of the female being almost precisely similar), according to the analyses of MM. Becquerel and Rodier :—

	Mean.	Max.	Min.
Saponified fat	1·004	2·000	·700
Phosphorized fat	·488	1·000	·270
Cholesterin	·088	·175	·030
Serolin	·020	·080	inappreciable.

The source of the peculiar *odour* of the blood, is probably a volatile fatty acid, too minute in its amount to admit of being separately estimated. This odour may be made much more apparent by treating the blood with sulphuric acid, even after it has been long dried; and in all those animals which are readily distinguishable by their odorous emanations, it may thus be made so perceptible as to admit of their blood being distinguished (at least by an individual possessed of a delicate sense of smell) through its scent alone. Of this test, use has been made with great advantage in juridical investigations.*

160. Under the vague term *Extractive*, have been included many different substances which normally present themselves in only very small quantity, and which are consequently very difficult of detection; but which are extremely important in a physiological point of view, as the chief 'factors' (to use the appropriate designation of Prof. Lehmann) in the metamorphosis of animal tissue, both *progressive* and *retrograde*. Amongst the latter, Urea, Creatine, Creatinine, Uric, Hippuric and Lactic Acids, Leucine, Tyrosine, Hypoxanthine (or Sarkin), and Lecithine, may be particularly mentioned. Besides the foregoing, the extractive of blood generally seems to contain Sugar, or an amyloid substance (Pavy), that is waiting for elimination by the respiratory process, this substance being found most abundantly, however, in the blood of the hepatic vein, vena cava, and pulmonary artery (§ 141). As might be expected, the proportion of sugar in the blood is greatly affected by the diet of the animal (§ 165).—The very small amount in which the Blood-constituents of this class normally present themselves, is readily accounted-for by the fact, that they are only *en route* between the tissues and the excretory organs which are destined for their elimination; so that as long as the disintegrating processes taking place in the former are balanced (as they should be) by the activity of the latter, these substances are withdrawn from the blood-current as fast as they are introduced into it, and no sensible accumulation will occur. It can scarcely be doubted that the more attentive study of this part of the blood, prosecuted upon large quantities at once, will be attended with the discovery of many facts that would throw great light upon the Chemistry of the histogenetic operations, and of the retrograde metamorphoses of the effete materials of the tissues.

161. No list of the *Inorganic Constituents* of the Blood which has yet been given expresses the precise mode in which they are grouped together. The proportion which the Carbonates bear to the Phosphates, however, seems to be small in Human blood; as is shown by the following table, founded on the analysis of Verdeil,† of the percentage composition of the ash of the blood, after deducting the carbon still contained in it:—

Man.	$NaCl$	NaO	KO	MgO	$SOgHO$	PO_5	$3CaO$ PO_5	Fc_2O_3	CO_2
I. ‡ .	61·99	2·03	12·70	0·99	1·70	7·48	3·55	8·06	1·43
II. § .	55·63	6·27	11·24	1·26	1·64	9·74	3·21	8·68	0·95

In Carnivorous animals the Phosphates, in Herbivorous the Carbonates, are in excess, which is obviously related to the difference of their diet. The proportion of Chloride of Sodium in both classes exhibits a remarkable constancy. The normal presence of various metals in the blood has been alternately admitted and denied. Millon* found in 100 parts of the insoluble residue of the ash of blood 1 to 3 parts of Silicium, 1 to 5 parts of Lead, 0·5 to 2·5 parts of Copper, and from 10 to 24 parts of Manganese.†

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* See M. Barruel's researches on this subject in "Ann. d'Hygiène," &c. tom. i. ii. x.

† "Ann. der Chem. und Pharm.," band lxix. p. 89.

‡ Man, forty-five years old, suffering from weak digestion.

§ Woman, twenty-two years old, sanguineous temperament.

162. We have now to inquire into the principal modifications which the relative proportions of these constituents undergo in the state of health, under the influence of varying conditions of the system; and notwithstanding the want of *absolute* correctness in the analyses of which we are at present in possession, those that are made by similar methods give results sufficiently trustworthy to enable them to be compared together, and thus to give a tolerably correct indication of the circumstances which determine the *increase* or *diminution* in the principal components of the Blood.—The first of these modifying conditions which requires special notice, is *Age*. During the latter part of fœtal life, the blood is remarkably rich in solid contents, as appears from the following comparative analyses of Denis: ‡—

	Venous Blood of Mother.	Blood of Umbilical Artery.§
Water	781·0	701·5
Solid constituents	219·0	298·5

The larger quantity of solid constituents in the blood of the fœtus is chiefly due to the increased proportion of corpuscles, which appears to continue for a short time after birth; but it gradually diminishes; and the whole amount of solid matter in the blood seems to fall to its lowest point during the period of childhood. Towards the epoch of puberty, however, the amount of solid matter increases again, the chief augmentation being in the corpuscles; and it remains at a high standard during the most vigorous period of adult life, after which it begins to decline. This is made apparent in the following table, deduced from the analyses of Denis, which are confirmed by those of Lecanu and Simon: ‖—

	Solid Constituents.
In 5 individuals between 5 months and 10 years	170
13 ,, ,, 10 years and 20 ,,	200
11 ,, ,, 20 ,, 30 ,,	240
12 ,, ,, 30 ,, 40 ,,	240
6 ,, ,, 40 ,, 50 ,,	240
8 ,, ,, 50 ,, 60 ,,	220
2 ,, ,, 60 ,, 70 ,,	210

163. An appreciable difference exists between the blood of the two *Sexes;* that of the male being richer in solid contents, and especially in corpuscles, than that of the female. On this point, the analyses of Lecanu, Denis, and Becquerel and Rodier are in accordance, notwithstanding their mutual discrepancies. From these it would appear that the *mean* excess of the whole solid constituents in the blood of the male, above those of the female, is reckoned by the several experimenters at from 12

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[*] "Annal. de Chim. et de Phys." sér. iii. t. xxiii. p. 372.

[†] Melsens ("Annal. d. C. et de P." xxiii. p. 358) denies the presence of Copper and Lead; and Béchamp ("Journ. de la Phys." 1860, vol. iii. p. 211) appears to think the occurrence of all or any of these metals to be merely accidental.

[‡] "Recherches Expérimentales sur le Sang humain," and Simon's "Animal Chemistry," vol. i. p. 238.

[§] Which has been shown by Poggiale to be identical with that of the body of Fœtus ("Comptes Rendus," t. xxv. p. 198).

[‖] "Animal Chemistry," vol. i. pp. 237-239.

to 20 parts in 1000; and that the variation is the greatest in the proportion of Corpuscles, neither of the other elements exhibiting any considerable difference in their amount in the two sexes. The excess in the solid constituents of the Male blood above those of the Female, is as well marked in the extreme as in the mean results; for the *maxima* in the female do not pass much higher than the *mean* of the male, whilst her *minima* fall far below his; on the other hand, the *maxima* of the male rise far higher than those of the female, whilst his *minima* scarcely descend below her *mean*.

164. It is obvious, from the extent of diversity shown in the analyses of these chemists, that the proportions of the constituents must vary considerably with individual *Temperament* and *Constitution*. All the persons whose blood furnished the subjects of their examination were (or considered themselves to be) in perfect health; but their standard of health could not have been by any means uniform. There is no doubt that, in individuals of the plethoric or 'sanguineous' temperament, the proportion of the whole solid constituents, and especially of the corpuscles, is considerably greater than in persons of the 'lymphatic' temperament; and it appears from the analyses of Lecanu,* that the sexual difference in the blood almost disappears, when the blood of males and of females of the latter temperament is compared.

165. A considerable influence is exercised on the entire amount, and on the relative proportions, of the constituents of the Blood, by the previous ingestion of *Food or Drink*, and by the *Diet* habitually employed. The observations hitherto made upon the first of these points, however, are not sufficiently numerous to admit of being generalized; and the chief points that can be definitely stated, are those which have been substantiated by Profrs. Buchanan and R. D. Thompson,† in their examination of blood whose serum exhibits the 'milky' appearance, which, when it occurs in health, is due to the entrance of chyle, more rapidly than its oleaginous matter can be eliminated by the respiration or appropriated by the tissues. When a full meal containing oily matter is taken after a long fast, and a small quantity of blood is drawn previously to the meal and at intervals subsequently, the serum, though quite limpid in the blood first drawn, shows an incipient turbidity about half an hour afterwards; this turbidity increases for about six hours subsequently, after which it usually begins to disappear. The period at which the discoloration is the greatest, however, and the length of time during which it continues, vary according to the kind and quality of the food, and the state of the digestive functions. Neither starch nor sugar, nor protein-compounds, alone or combined, occasion this opacity in the chyle; but it seems essentially dependent upon an admixture of *oleaginous* matter with the food. There are few ordinary meals, however, from which such matter is altogether excluded. When such milky serum is examined with the Microscope, the opacity is found to be due to the presence of an immense number of exceedingly minute granules, resembling in appearance those which form the 'molecular base' of the chyle (§ 124). They seem to be composed of two chemically-distinct

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* "Etudes Chimiques sur le Sang humain," p. 66; and Simon's "Animal Chemistry," vol. i. p. 236.

† "Medical Gazette," Oct. 10, 1845.

substances; for when the milky serum is agitated with ether, a part is dissolved, whilst another portion remains suspended; and this latter is soluble in caustic potass. The former, therefore, appears to be identical with the 'molecular base' of the Chyle, and to be of an oily or fatty nature; whilst the latter belongs to the protein-compounds. The Crassamentum of such blood often exhibits a pellucid fibrinous crust, sometimes interspersed with white dots; and this seems to consist of an imperfectly-assimilated protein-compound, analogous to that found in the serum. The quantity of this varies according to the amount of the protein-compounds present in the food.—The increase of *saccharine* matter in the blood (in which it forms part of the 'extractive'), after the ingestion of a large quantity of saccharine or farinaceous aliment, has been noticed by many experimenters, and has lately been made the subject of attentive study by Von Becker.* He has found that the blood of Rabbits fed on carrots, contained 0·584 per cent of sugar, whilst that of rabbits fed on oats contained only 0·109 per cent; the blood of the same animals after 24 hours' starvation, contained only 0·045 per cent; whilst as much as 1·198 per cent was found in the blood of a rabbit, into whose food so large an amount of sugar had been introduced that it passed away with the excrements. The proportion contained, however, in the blood of Oxen, Dogs, and Cats, is far smaller than this; being (according to the researches of Schmidt)† from 0·00069 to 0·00074, 0·0015, and 0·0021 per cent respectively.—It might be fairly presumed that a temporary augmentation must take place in the *aqueous* constituent of the blood, whenever any considerable quantity of liquid is ingested; and yet this augmentation is much less considerable, under ordinary circumstances, than we should at first be inclined to suppose. For there exist various provisions in the system (the peculiar Malpighian apparatus of the Kidneys being the chief) for rapidly freeing the blood from any superfluity of water; and thus any excess of fluid absorbed is speedily drawn-off again. But further, it is certain that when the vessels are already filled, absorption does not take place with nearly the same readiness as after long abstinence from liquids (§ 108); the rate of absorption being in great degree governed by that at which the liquid is disposed-of. It follows, therefore, that the absorption of even a considerable amount of water within a short time, need not really involve any great dilution of the blood; and it is probable that a considerable reduction of its density will be thus produced in a state of health, only when it has first undergone an unusual elevation, in consequence of the removal of part of its water by perspiration, diuresis, &c., without a corresponding replacement of it by absorption.—The influence of the *Regimen* upon the composition of the blood, however, appears to be more definite and constant. An animal diet tends to increase the whole amount of solid matter, but especially to augment the proportion of corpuscles. On the other hand, a vegetable diet tends to lower the whole amount of solid matter, occasioning a marked reduction in the corpuscles, whilst it seems rather to increase the albumen; thus showing that the decrease in the corpuscles is not due to a deficiency in their azotized pabulum, but depends on some other condition. The development of fibrin appears to take place at least as readily on the vegetable, as on the animal regimen. Hence we see what may, and what may not, be effected in the treatment of disease, by the adoption of a particular dietetic system; for we may promote or retard the development of the red corpuscles by the employment of an animal or a vegetable regimen, but can make little or no impression upon the fibrin.*—The effect of complete *abstinence* from food, also, or of a continued insufficient supply of it, is to reduce the proportion of the whole solid constituents; but in this case, too, the corpuscles are much more reduced than the albumen; and very little effect is produced upon the fibrin, which at once undergoes an absolute increase if any inflammatory affection should develope itself.

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* "Zeitschr. für wissenschaft. Zool.," 1853, cited in Prof. Lehmann's "Physiologische Chemie," 2nd edit., band ii. p. 217.

† "Charakteristik der Cholera," §§ 161-164.

166. The effect of *Loss of Blood* is of a very similar nature to that of abstinence. Almost as soon as the stream begins to flow from a wounded vessel, there seems to be a transudation of watery fluid from the tissues into the current of blood; for this undergoes a rapid diminution in density, so that the portion last drawn is of lower specific gravity, and contains a considerably smaller amount of solid matter, than that which first issued. This fact, which has long been known, has of late been more precisely determined by Drs. Zimmerman,† Polli,‡ and J. Davy,§ from whose observations, as well as from the results of the analyses of MM. Becquerel and Rodier, it appears that the special effect of bleeding is to lower the proportion of red corpuscles, whilst it has no power of effecting a diminution in the amount of Fibrin, Albumen, Extractive and Saline matters, or Fat. We shall find, indeed, that in inflammatory diseases the amount of fibrin undergoes an extraordinary increase (§ 178), which is not checked in the slightest appreciable degree by the most copious venesection. It is remarkable that after very considerable losses of blood, a decided increase shows itself in the proportion of Colourless corpuscles, not only *relatively* (as to the red) but *absolutely*; so that, in the blood of a Horse from which 50 lbs. have been previously abstracted, the coloured and the colourless corpuscles appear to exist in equal numbers.||

167. We have now to consider the differences which present themselves in the composition of the Blood drawn from different vessels of the same body; these, it is obvious, being dependent on the changes to which the fluid is subjected, during its passage through organs that will appropriate or change its several constituents in an unequal degree. And the first and most important of these sets of differences, is that which exists between *Arterial* and *Venous* blood. The analyses already cited having been made chiefly upon the latter, it will be sufficient here to state the general results of comparative inquiries into the composition of the former. The quantity of solid constituents pertaining to the *Corpuscles* is smaller; they contain relatively more hæmatin and salts, but

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* See on this subject the treatise of M. Emile Marchand, "De l'Influence comparative du Régime Végétal et du Régime Animal sur le Physique et le Moral de l'Homme."

† "Heller's Archiv," band iv. p. 385.

‡ See "Medico-Chirurgical Review," Oct., 1847.

§ "Anatomical and Physiological Researches," vol. ii. p. 28.

|| Kölliker's "Manual of Human Histology" (Sydenham Society's edit.), vol. ii. p. 330.

much less fat. The liquor sanguinis is somewhat richer in *Fibrin;* but it contains a larger proportion of water, and consequently less *Albumen.* The *Fatty matters* of the serum, as well as of the corpuscles, are considerably diminished; on the other hand, the *Extractive and Saccharine matters* are decidedly increased. It is affirmed by Dr. G. O. Rees,[*] that the phosphorus which exists in venous blood in an unoxidized state, united with the fat of the corpuscles, is converted by the respiratory process into phosphoric acid, which passes into the serum and unites with alkaline bases; and this view seems borne out by the more recent analyses of Reich.[†]—The most remarkable difference between Arterial and Venous blood, however, lies in the amount of *gases* which they respectively contain.

168. *Pneumatology of the Blood.*—The Gases contained in the blood chiefly consist of Carbonic acid and Oxygen. A small proportion of Nitrogen and traces of Ammonia are, however, constantly present. In 100 volumes of blood are found rather less than 50 volumes of these gases collectively; but their total quantity, as well as their relative proportions, present considerable variations in different parts of the body. From the results of numerous recent researches the conclusion may be drawn, that the affinity or capacity of absorption of the blood for the two first-named gases at least, is peculiar, follows laws of its own, and differs materially from that of other liquids. If we compare it, for instance, with water, we find that whilst 100 vol. of water will take up 2·97 vol. of Oxygen at standard temperature and pressure, the same quantity of blood, at 32° F., will absorb from 16·882 vol. to 19·794 vol.;[‡] and the amount absorbed appears to be but slightly affected by the degree of pressure to which the fluid is subjected, though according to the experiments of Bernard[§] it varies to a considerable extent in blood drawn from different regions of the body. Thus whilst 100 vol. of arterial blood absorbed 8·9 vol. of Oxygen, the same quantity of blood taken from the Jugular Vein absorbed 16 vol., from the Right Heart 21·1 vol., and from the Portal Vein 30 vol. of this gas. In a similar manner, whilst 100 vol. of water will absorb about 100 vol. of Carbonic acid at ordinary temperature and pressure, Meyer[||] found that 100 vol. of fresh defibrinated blood would take up 178·3 vol. of Carbonic acid at 48° F.; the quantity increasing, though not in direct proportion, with the pressure. Even as regards Nitrogen, the Blood appears to possess a superior power of absorption than pure water, 100 vol. of the latter absorbing at ordinary temperature and pressure about 1·5 vol. of nitrogen, while 100 vol. of fresh defibrinated Blood deprived of gas by exhaustion will absorb about 5 vol. at a temp. of 65° F. and under a pressure of 0·6 m. (Setschenow). It is very evident then that the absorption of these gases does not take place in accordance with the ordinary law established by Dalton and Henry, but that chemical affinity must come into play; and the investigations of

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[*] "Philosophical Magazine," vol. xxxiii. p. 28.

[†] "Archiv der Pharmacie," and "Liebig and Kopp's Report" for 1849, p. 366.

[‡] Setschenow, 'Beitrage zur Pneumatologie des Blutes,' "Sitzungsbericht d. k. Akad. d. Wissens." xxxvi. 1859, p. 293. See also Fernet, "Annal. de Scien. Nat.," 1858, tom. viii. p. 125.

[§] "Leçons," 1859, tom. i. p. 282.

[||] "Zeitschrift f. Rat. Med.," band viii. p. 256.

Meyer, Fernet, Heidenhain,* and others indicate that the Carbonic Acid present in the blood may be divided into two portions, of which one follows the ordinary law of absorption, whilst the absorption of the other is only explicable on the supposition of there being certain substances in the blood for which it possesses a strong affinity, and with which it enters into combination. These substances appear to be the Carbonate and Phosphate of Soda contained in the Liquor Sanguinis, for dilute solutions of both these salts in pure water exert a well-marked influence in increasing the quantity of Carbonic Acid which can be absorbed; in the former case a bicarbonate of the alkali being formed, and in the latter case a peculiar double salt, represented, according to Fernet, by the formula $PO_5 + 2\,Na\,O\,HO + 2\,CO$.†—As regards the Oxygen contained in the Blood, there seems every reason to believe that it is altogether present in the state of chemical combination with some constituent of the Red Corpuscles: since, in the first place, it has been shown by Bernard‡ that a solution of pyrogallic acid, the affinity of which for oxygen is well known, will not abstract it when injected into the vessels, the acid reappearing unchanged in the urine; whilst the observations of Berzelius long ago proved that serum alone possesses no greater power of absorbing oxygen than pure water. The importance of the absorption of this gas being dependent upon chemical affinity and not simply upon pressure, is sufficiently obvious; since, by securing the introduction of a definite proportion of this gas, it enables animal life to be maintained without difficulty at all altitudes, and under the most various conditions of atmospheric pressure.

169. The actual quantity and relative proportions of the Gases contained in the Blood, as well as the exact ratio of the combined to the simply absorbed gases, is still a matter of question. The following table gives the most recent observations on this subject:§—

In 100 Vols.	Total Quantity of Gas contained in the Blood.	Free Gas.	Oxygen.	Nitrogen.	Carbonic Acid.			Observer.
					Free.	Combined.	Total.	
Arterial Blood (Dog)	49·49	20·88	12·43	2·83	5·62	28·61	34·23	Meyer
Ditto	54 08	25·50	14·29	5·04	6·17	28·58	34·75	,,
Defibrined Calf's Blood	35·16	17·04	11·55	4·40	1·09	18·12	19·21	,,
Arterial Blood of Dog	49·44	46·90	15·05	1·19	30·66	2·54	33·20	Setschenow
Human Blood . .	48·20	45·88	16·41	1·20	28·27	2·32	30·59	,,
Arterial Blood of Dog	46·22	—	11·39	4·18	—	1·90	30·08	Schöffer
Venous Blood of same animal	—	—	4·15	—	—	5·49	29·32	,,
Arterial Blood of Dog	41·32	—	9·88	1·54	—	—	29·90	Nawrocki

It will be observed that whilst the total quantity of Gases contained in the Blood is given at nearly the same amount by all observers, there

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[*] "Studien des Physiolog. Inst. zu Breslau," 1863, p. 103.

[†] Heidenhain's experiments show that this statement only holds for very dilute solutions.

[‡] Bernard, "Leçons," 1859, vol. i. p. 337.

[§] See Henle and Meissner, 1857, 1859, p. 303, 1860, p. 330; v. Gorup-Besanez, "Phys. Chemie," 1862, p. 322.

is a wide difference in the proportions assigned by Meyer and Setschenow respectively to the free and combined Carbonic acid. The results of Setschenow are probably the more accurate, as he kept the Blood in a very perfect vacuum for a longer period, and maintained it at a temperature of about 100° F., a point which had been previously neglected. Supposing the result obtained by this observer to be correct, it follows, as Fernet observes, that there can be but little Bicarbonated Alkali in the Blood, since this will not give up its CO_2 to mere exhaustion; and we must conclude that the Carbonic Acid taken up in excess of the ordinary law of absorption is due to the Phosphate of Soda contained in the Serum of the Blood.—The percentage proportion of the Gases of the Blood amongst themselves, obtained from the mean of seven observations of Meyer and Setschenow, is—

Oxygen	28·20
Nitrogen	7·10
Carbonic Acid	64·70
	100·0

In all experiments made to determine the proportions of the Gases of the Blood, the investigation should be commenced immediately after the blood has been withdrawn; since it is certain that the quantity of Oxygen decreases, and of Carbonic Acid increases, with considerable rapidity. Thus Felix Nawrocki* found the following differences in two equal and similar portions of blood drawn at the same time, one of which (I.) was examined immediately, and the other (II.) after the lapse of 24 hours, the mean temperature of the air in which was 86° F.:—

	I.	II.	
CO_2	34·66	40·95	
O	7·72	1·02	
N	1·97	0·67	
	44·35	42·64	Vol. in 100 of Blood.

The variation which occurs in the proportion of the several Gases in different kinds of Blood is well shown in the following results obtained by Sczelkow,† where A indicates Arterial blood, MR the blood returning from muscles at rest, and MA that returning from muscles in action:—

Total Gas.		O	N	Free CO_2	Combined CO_2	Total CO_2
A	43·515	17·334	1·636	24·204	0·341	24·545
MR	40·450	7·5	1·364	31·036	0·550	31·586
MA	37·069	1·265	0·923	34·443	0·438	34·881

In other experiments Sczelkow found that the venous blood returning from muscles at rest contained on the average 6·71 per cent more Carbonic acid and 9 per cent less Oxygen than arterial blood, whilst that returning from muscles in action contained an excess of 10·79 per cent of Carbonic acid, and a deficit of from 12 to 14 or even 16 per cent of Oxygen; and similar results were obtained by Bernard.‡ From the inquiries of His,* it appears that the Blood-Corpuscles possess peculiar relations to Ozone, absorbing that allotropic condition of Oxygen with considerable energy, but parting with it again with equal facility, and acting therefore pre-eminently as Ozone carriers.

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* See "Studien des Physiolog. Institut zu Breslau," 1863, p. 144.

† "Sitzungsbericht d. Wiener Akad.," band xlv., 1862.

‡ "Leçons," vol. ii. 1859, p. 435.

170. The increase of the Fibrin, however, which seems to be effected during the aeration of the Blood, must be taken as an indication that a certain part of the oxygen absorbed from the air is made directly subservient to changes in the composition of the circulating fluid; and it appears from certain of its reactions, that the fibrin of arterial blood must be in a state of higher oxidation than that of venous. Now although the differences between fibrin and albumen lead us to regard the production of the former from the latter as rather a *vital* than a *chemical* change, yet the existence of the difference in question obviously points to the presence of oxygen as a condition essential to its performance; and this inference is fully confirmed by the experiments of Dr. Gairdner,† on the influence of the respiration of pure oxygen on the production of fibrin. As the Rabbit was on many accounts the most convenient warm-blooded animal for such a trial, he first set himself to determine the normal proportions of the constituents of its blood. The analysis of the blood drawn from the aorta in six healthy individuals, yielded the following results:—

	Mean.	Max.	Min.
Fibrin . . .	1·65	2·00	1·45
Corpuscles . .	82 35	92·00	70·00
Albumen . . .	46·30	58·00	37·20

On the other hand, the analysis of the blood of three individuals which had been made to respire pure oxygen for half an hour, gave the following as the proportions of its components:—

	Mean.	Max.	Min.
Fibrin . . .	2·40	2 50	2·30
Corpuscles .	69·56	75·00	60·50
Albumen . . .	40·23	45·70	35·00

It is further stated by Dr. Gairdner,‡ that a rabbit having been kept for half an hour under the influence of an electro-magnetic current between the chest and spine, which produced a great acceleration in the respiratory movements, its blood was found to contain as much as 2·9 parts of fibrin in 1000.§—The larger quantity of fibrin in arterial blood of itself renders its coagulum firmer; but independently of this, there would seem to be a difference in the quality of the fibrin, which, when separated by stirring or whipping, is more tenacious and compact in arterial than in venous blood.

171. The proportion of Red Corpuscles in arterial and venous blood respectively, has been variously stated by different observers; and we may easily conceive it to be affected by several circumstances, which may produce a change in the whole proportion of the solid to the fluid con-

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* "Journal de la Physiol.," vol. i. 1858, p. 634.

† Treatise "On Gout," 2nd edit., pp. 153-4.

‡ Op. cit., p. 183.

§ More recently Mr. A. H. Smee ("Proceedings of the Royal Society," 1863), and v. Gorup-Besanez ("Physiolog. Chemie," 1862, p. 137) have stated that they have obtained a fibrin-like substance; the former, by transmitting Oxygen, and the latter Ozone, through an albuminous fluid.

stituents of the blood, during the course of its circulation. Thus, discharge of the contents of the thoracic duct into the venous system n the heart, will tend to dilute the blood of the pulmonary and arte circulation; whilst, conversely, the escape of the watery part of the bl by the renal and cutaneous secretions, and by transudation into tissues, which takes place during its passage through the systemic ca laries, will tend to augment the proportion of the solids of the bl drawn from the systemic veins. On the other hand, if the discharge fluid from the thoracic duct be suspended, and the amount absorbed fr the tissues during the systemic circulation should exceed that which transuded (as appears sometimes to happen, § 166), then the proport of solid matter will be less in venous than in arterial blood.—No s explanation will apply, however, to the very marked differences exhibi in Dr. Gairdner's experiments just cited, between the proportions of corpuscles and of albumen in the ordinary arterial blood of rabbits, a in that of the individuals whose blood had been hyper-arterialized; sum of the averages in the former case being 128·65, and in the lat 109·79, the difference of which is 18·86, or nearly *one-seventh* of the lar amount. Still, that this difference is in great part due, rather to dilut of the blood, than to the absolute diminution in its entire amount of corpuscles and of albumen, would seem probable from the fact that th *relative* amount is almost exactly the same in the two cases, the prop tion of corpuscles to albumen being 1·78 :1 in the normal blood, a 1·72 : 1 in the oxygenated.*

172. The difference in the *colour* of arterial and of venous blood, whi is entirely dependent upon the state of the Red Corpuscles, has b commonly supposed to be produced by a chemical change exerted up their Hæmatin by oxygen and carbonic acid respectively. Of such chan however, there is no adequate evidence; and there are many indicati that we are to look for the source of the difference of colour, rather modifications in the *form* of the corpuscles, affecting their power of tra mitting and reflecting light, than in any chemical alterations of th *contents*. It is true that if arterial blood be exposed to carbonic acid of the body, it will acquire the dark hue of venous blood; whilst, co versely, venous blood exposed to oxygen will acquire (on its surface least, the florid hue of arterial blood. But for these changes to ta place, it is necessary that the normal proportion of saline matter sho exist in the serum in which the corpuscles float. For if arterial blo deprived of its fibrin be diluted with twice or thrice its volume of wat it assumes a dark venous tint, which is not affected by the passage o current of oxygen through it; yet the red colour is restored by t addition of a saturated solution of a neutral salt, even without the cont of oxygen. On the other hand, venous blood is reddened by the additi of a strong saline solution, without any exposure to oxygen; and it is r readily darkened again by the passage of carbonic acid through it. Aga a scarlet clot is darkened by washing it with distilled water, and is on very slowly reddened by exposure to oxygen; whilst a black clot becom at once scarlet when it is washed with salt, and is not blackened again

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carbonic acid. Further, if the corpuscles be treated with water until the hæmatin is diffused through the liquid, scarcely any effect is produced upon the hue of the solution, either by carbonic acid, by oxygen, or by salines; such slight alteration as does occur being fairly attributable to the influence which the absorption of these gases may produce upon the colouring matter, without entering into chemical combination with it.—Hence it is obvious that the light or dark colour of the blood affords no indication whatever of its state of oxygenation, since the change from the one to the other may be effected by other agents; and if we examine into the nature of their influence, we find that the blood is *darkened* by whatever tends to *distend* the corpuscles, so as to render them flat or bi-convex, whilst it is *brightened* by whatever tends to *empty* them, so as to render them more deeply bi-concave than usual.* The varying circumstances under which either arterial or venous blood may be at one time dark and at another scarlet in colour, have been very fully discussed by Bernard.† He observes that in the Fœtus, and in the asphyxiated animal, the blood is everywhere dark or venous. On the contrary, during sleep, in the hibernants during the period of repose, and in animals dying by anæmia, the blood is everywhere scarlet or arterial. With high temperatures of the surrounding medium, whether this be air or water, there is little difference in the colour of the two kinds of blood, the arterial being less and the venous more florid than usual.‡ The difference between them is, on the other hand, best marked in cold weather. The Blood contained in the veins of muscles is dark, and always of a deeper shade in proportion to the energy and duration of the previous muscular contraction, whilst that returning from the glands is always brighter in proportion to the activity with which secretion is being performed; and in the latter instance, with the alteration in colour, the amount of fibrin is found to be diminished, or so modified as to form a softer clot, from which a larger quantity of serum separates. It is remarkable that if the dark-coloured clot of ordinary venous blood be immersed in the serum of the scarlet venous blood, it rapidly assumes a brighter tint, and conversely the clot of scarlet venous blood changes to a dark colour when immersed in the serum of deep-coloured venous blood; from which we may conclude that the primary changes are effected upon the Liquor Sanguinis, and not upon the corpuscles. The influence of the Nervous System in inducing alterations in the colour of the blood returning from glands has already been pointed out (§ 80).

173. Although no difference can be detected between samples of blood drawn from various parts of the *Arterial* system of the same animal, very important variations exist, as might be expected, in the composition of the blood drawn from the several parts of the *Venous* system; since the changes to which it has been subjected in the several organs through which it has passed, are of a very diversified character. The blood of the Vena Portæ, for example, differs considerably from the blood of the Hepatic

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* Messrs. Todd and Bowman ("Phys. Anat," vol. ii. p 298) were, however, unable to discern any difference in form under the microscope between the Corpuscles of Venous and Arterial Blood.

† "Leçons," xi. to xix., 1859.

‡ See an account of Davy's and Crawford's Experiments in Gulliver's Lectures, "Med. Times and Gaz.," 1863, vol. i. p. 1.

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† "Leçons," xi. to xix., 1859.

‡ See an account of Davy's and Crawford's Experiments in Gulliver's Lectures, "Med. Times and Gaz.," 1863, vol. i. p. 1.

vein, and both of these differ from the blood of the Jugular. So, again, the blood of the Splenic as well as that of the Renal vein differs from all the preceding. The most important and best-established of these diversities will now be enumerated.—In speaking of the composition of the blood of the *Vena Portæ*, it must be remembered that this consists of two very distinct factors, namely, the blood of the Gastric and Mesenteric veins, and the blood of the Splenic vein; the former having been altered by the introduction of solid and liquid alimentary matters, and the latter by its circulation through the spleen. These, therefore, ought to be separately studied; and this has been done by M. Jules Béclard.* The characters of the blood returning by the *Gastric* and *Mesenteric* veins from the walls of the alimentary canal, are of course affected by the stage of the digestive process, and by the nature and amount of the absorbable matters. As compared with the ordinary venous blood, the total quantity of its solid constituents is lowered during the early part of the digestive process, by the dilution it suffers through the imbibition of liquid; and this diminution is especially remarkable in the corpuscles, the relative proportion of albumen being increased by the introduction of new albuminous matter from the food. Towards the conclusion of the digestive process, however, the blood of the mesenteric veins gradually comes to present the ordinary proportions of these two components; and in an animal that has been subjected to long abstinence, it does not differ from that of the venous system in general. The quantity of extractive is usually increased; and in this part of the blood it must be, that sugar, dextrin, gelatin, and other soluble organic matters that are taken into the circulation, are contained. Some of these have in fact been detected in it.† The fibrin of the blood of the mesenteric veins appears to be less perfectly elaborated than that of the blood in general; for the blood of the mesenteric veins coagulates less firmly (having been erroneously asserted by some not to coagulate at all); and its fibrin, when separated by stirring, shows a marked deficiency in tenacity, and liquefies completely in the course of a few hours. A part of the albuminous constituent of this blood does not present the characters of true albumen, for it is not precipitated by heat or by nitric acid, and the precipitate thrown-down by alcohol is redissolved by water; like albumen, however, it is precipitated by the metallic salts, creosote, and tannin. This substance, which has been distinguished by M. Mialhe as *albuminose*, further differs from true albumen in the facility with which it traverses organic membranes; for these resist the passage of albumen, while they are freely transuded by albuminose. And it is affirmed by M. Mialhe, that the want of that conversion of albuminose into albumen, which ought to take place as part of the assimilating process, is one cause of the readiness with which albuminous matter transudes from the blood in albuminuria and in dropsies; this albuminous matter frequently having rather the characters of albuminose, than those of true albumen.‡

174. That the Spleen ordinarily effects a marked change in the con-

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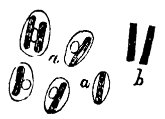
* See his Memoir in the "Arch. Gén. de Méd.," 4e série, tom. xviii. p. 322 *et seq.;* and his edition of his father's "Elémens d'Anatomie Générale," pp. 265, 266.

† See the Researches of MM. Bouchardat and Sandras in the "Supplément á l'Annuaire de Thérapeutique," 1846.

‡ See the "Cours de Physiologie" of M. Paul Bérard, tom. iii. p. 87.

stitution of the blood which passes through it, appears from the analyses made by Mr. Gray and M. Béclard,[*] of the blood drawn from the interior of the organ itself after its removal, the splenic vein having been previously tied. The nature and amount of these changes, however, differ in a very marked degree, according to the stage of the digestive operation and the general condition of the nutritive functions; and it is to this circumstance that we are probably to ascribe much of the diversity in the results obtained by previous experimenters. A marked decrease in the total amount of solid matter is generally observable; the average of twelve experiments giving only 187·1 per 1000 of solid constituents in the splenic blood, whilst the arterial blood of the same animals contained 239 parts, and the jugular venous blood 201 parts. This decrease depends upon the diminished proportion of *red corpuscles*, which seems always to present itself, except in starved or extremely ill-fed animals. On the other hand, the *albumen* usually exhibits a marked increase, which may even double its previous amount; and this seems greatest at an interval of some hours after feeding. The *fibrin* seems to be almost constantly augmented, and this sometimes in a very remarkable degree; the quantity found in the splenic blood varying from 2·5 to 11·53 parts in 1000, or from an amount a little above the usual standard, to nearly six times that average.[†] The blood of the Splenic vein is further remarkable for the large proportion of colourless corpuscles (apparently derived from the white portion of its parenchyma) which it includes. Hirt[‡] counted 1 colourless to 2179 coloured corpuscles in the Blood of the Splenic Artery, but 1 colourless to 60 coloured in that of the Splenic Vein; and the latter is also remarkable for containing a number of fibrinous flakes and of peculiar cells including rod-like crystals of reddish-yellow colouring matter (Fig. 42), which seem to be red corpuscles in a state of degeneration.

FIG. 42.



Blood-corpuscles with rod-like yellow crystals, from Splenic Vein of *Perch*; *a*, blood-cells, treated with water; *b*, free crystals.

175. Many comparative observations have been made upon the blood of the *Vena Portæ* and of the *Hepatic vein;* but a large part of them, according to M. Cl. Bernard, are vitiated by the fact, that, unless the vena portæ be tied, a reflux of blood takes place into it from the liver, so that the blood which flows when it is wounded, is not so much portal as hepatic blood. According to this experimenter, the blood of the hepatic vein is peculiar as containing an increased proportion not only of sugar but also of fat; these substances being generated, during the passage of the blood through the liver, not only from amylaceous or other saccharine matters, but even from azotized compounds. The production of fat is to a certain degree vicarious with that of sugar; and the former

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[*] "On the Structure and Uses of the Spleen," 1854.

[†] It seems obvious that such an enormous diminution of the Red Corpuscles can only take place in blood which is partially or completely *stagnated* in the organ; since, if the circulation through it were taking-place at the usual rate, all the blood in the body would be speedily subjected to the process, and its corpuscles would be (as it were) entirely melted down.—For a statement of Mr. Gray's views, with critical observations thereon, see the "Brit. and For. Med.-Chir. Rev.," Jan. 1855.

[‡] "Müller's Archiv," 1856.

is characteristic of herbivorous, the latter of carnivorous animals. According to Prof. Lehmann, the blood of the hepatic vein differs from that of the portal in the following particulars. "It is far poorer in water; so that, assuming the solid constituents of the blood to be equal in both kinds of blood, the quantity of water in the blood of the portal vein is to that in the blood of the hepatic vein as 4:3 during digestion and when not much drink has been taken, and sometimes as much as 12:5 after digestion has been fully accomplished. The blood of the hepatic vein either does not coagulate at all, or the clot is bulky and readily breaks down. Whilst 34 parts of serum are separated from 100 parts of portal blood, only 15 are separated from 100 parts of the blood of the hepatic vein. The blood of the hepatic vein is far richer in blood-cells, both coloured and colourless, than that of the portal vein; the colourless corpuscles occur in the most varied shapes and sizes; Hirt estimated that the proportion of the colourless to the red corpuscles was in the portal venous blood as 1:524, in the hepatic as 1:136; the coloured are seen in heaps of a distinct violet colour, and their cell-walls are less readily destroyed by water than are those of the blood of most other vessels. The cells in the blood of the hepatic veins are poorer in fat and in salts, and especially in hæmatin, or at least iron, but somewhat richer in extractive matters. Their specific gravity is higher than that of the cells of the portal blood, notwithstanding the diminished quantity of iron. The plasma of the blood of the hepatic veins is far denser than that of the blood of the portal vein, for it contains a much larger amount of solid constituents generally, although little or no fibrin is to be found in it. If we compare the solid constituents of the serum of both kinds of blood, we find less albumen and fat, and far less salts, in the blood of the hepatic vein, while the quantity of extractive matter, including sugar, is perceptibly augmented."* It cannot be doubted that when the secretion of urine is proceeding with rapidity, the blood of the *Renal vein* must contain a smaller proportion of water than that of the renal artery, and that the quantity of salines also must be diminished; since a separation of these ingredients takes place in the passage of the blood through the renal capillaries. So far as regards the quantity of water, this *à priori* conclusion has been confirmed by the analyses of Simon, who found 790 parts of water in 1000 of blood drawn from the renal artery, and only 778 in blood drawn from the renal vein of the same animal.† And Picard‡ found in the renal arterial blood of two dogs 0·0365 and 0·04 per cent of Urea, whilst in the venous blood returning from the kidneys the proportion was 0.0186 and 0·02 per cent. Poisseuille and Gobley,§ however, did not find the difference so well-marked or constant.

176. *Alterations in the Composition of the Blood in Disease.*—Under this head it is intended here to consider, not the state of the Blood in every principal type of disease (which it is the duty of the Pathologist to investigate), but the most important facts which the study of its morbid conditions has afforded, towards the determination of the con-

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* "Physiological Chemistry" (Cavendish Society's ed.), vol. ii. p. 259; Lehmann, "Leipziger Berichte," iii. 131; and "Pharmaceut. Central Blatt," 1856, p. 433.

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ditions under which decided variations take place in the quantity or quality of its principal components, and of the effects which those variations produce upon the system at large. Many analyses have been made by excellent observers;* but in consequence of the variations in the mode of analysis pursued, the results can only be given in general terms.

177. The first of these components whose variations we shall consider, is *Fibrin;* the estimate of which, however, is open to an important fallacy, that has not been sufficiently guarded-against,—namely, the admixture of the Colourless corpuscles. "These," as Mr. Paget correctly remarks, "cannot, by any mode of analysis yet invented, be separated from the fibrin of mammalian blood; their composition is unknown, but their weight is always included in the estimate of the fibrin. In health, they may, perhaps, add too little to its weight to merit consideration; but in many diseases, especially in inflammatory and other blood-diseases in which the fibrin is said to be increased, these corpuscles become so numerous that a large proportion of the supposed increase of the fibrin must be due to their being weighed with it. On this account, all the statements respecting the increase of fibrin in certain diseases need revision."†—In the results of the analyses now to be stated, it must be borne in mind that the term 'fibrin' really designates the 'colourless coagulum' of spontaneous formation, whatever may be its composition. The following may be considered as the normal range of variation for the principal constituents of the blood in health, according to the mode of estimating them pursued by MM. Andral and Gavarret:—

Fibrin	from	2	to	3½	parts per 1000.
Red Corpuscles .	„	110	„	152	„ „
Solids of Serum .	„	72	„	88	„ „
Water	„	760	„	815	„ „

178. The most important fact substantiated by Andral, is one that had been previously suspected,—the invariable increase in the quantity of Fibrin during acute Inflammatory affections; the increase being strictly *proportional to the intensity of the inflammation, and to the degree of* symptomatic fever accompanying it. "The augmentation of the quantity of Fibrin is so certain a sign of Inflammation, that, if we find more than 5 parts of fibrin in 1000, in the course of any disease, we may positively affirm that some local inflammation exists." The average proportion of Fibrin in Inflammation may be estimated at 7; the minimum at 5; the maximum at 13·3. The greatest augmentation is seen in Pneumonia and Acute Rheumatism. An increase is also commonly observable during the advanced stage of Phthisis, in spite of the deterioration which the blood must then have undergone, and this is probably dependent upon the development of local inflammation around the tubercular deposits. In Continued and Typhoid Fevers, whilst the proportion of Corpuscles is commonly increased, there is a decrease in the proportion of Fibrin, especially in the early stage; though the usual augmentation will take place if any local inflammation occurs. It appears from the experiments of Magendie, that one of the effects of a diminution in the proportion of Fibrin is a tendency to the occurrence of Hæmorrhage or

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* See Andral and Gavarret, "Essai d'Hæmatologie Pathologique;" Becquerel and Rodier, "Recherches sur la Composition du Sang," &c.

† Kirkes and Paget's "Handbook of Physiology," p. 57.

of Congestion, either in the parenchymatous tissue or on the surface of membranes; and these conditions are well known to constitute common complications, not only of febrile diseases, but also of Apoplexy and Purpura hæmorrhagica, in both of which there is a marked deficiency of Fibrin. It has been asserted that the proportion of Fibrin is diminished in Scurvy; but this, from the analyses of MM. Becquerel and Rodier, Chatin and Bouvier,* and Mr. G. Busk,† appears not to be the case, the proportion of fibrin being rather above than below the normal average. In Cholera, however, a reduction in the coagulable element of the blood seems to be an almost constant occurrence; and in some instances, the blood, although loaded with solid matter, has scarcely coagulated at all. Of the blood drawn during life, it has been observed that the clot is loose and grumous, often not shrinking and expelling serum; and that this change presents itself in a degree corresponding to the severity and advanced stage of the disease. And when the blood has been removed from the body after death, the clots have been found loose and fragile in texture, sometimes almost semi-fluid.‡ The increase in the fibrinous constituents of the blood in Inflammation, as long ago maintained in previous editions of this work, is not dependent upon the febrile condition that is secondary to the local inflammation, but upon the Inflammation itself: Virchow,§ from careful observations, has been led to express similar views on this subject, remarking that the fibrin is not primarily developed in the blood, but is a purely local production, being originally formed in the tissues of the inflamed part externally to the vessels, and being subsequently taken up by the Lymph-tubes, and by them conveyed to the blood. The so-called "exudation" which is supposed to form the greater part of the swelling in Inflammation, and which is usually regarded as an effusion from the congested vessels of the part, is in his opinion merely the surplus fibrin, formed *in loco*, for the removal of which the lymphatic circulation is not sufficiently active.

179. The amount of *Red Corpuscles* seems to be subject to greater variation within the limits of ordinary health, than is that of fibrin. In the condition which is ordinarily termed a highly sanguineous temperament, or Plethora, it is chiefly the entire mass of the blood that undergoes an increase; but whatever excess there may be in the proportion of its solid constituents, this affects the Corpuscles rather than the fibrin. Plethoric persons are not more prone to Inflammation, than are those of weaker constitution; but they are liable to Congestion, especially of the brain, and to apoplexy or other hæmorrhage. The effect of bleeding in diminishing this tendency is now intelligible; since we know that loss of blood reduces the proportion of corpuscles.—On the other hand, in that temperament‖ which, when exaggerated, becomes Anæmia, there is a marked diminution of the Corpuscles; and this temperament may lead, on the one hand to Chlorosis, in which the Red Corpuscles are diminished

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* "Journ. de Chimie Médicale," Mars, 1848.

† "Library of Medicine," vol. v. p. 90.

‡ See Dr. Parkes' "Researches into the Pathology and Treatment of the Asiatic or Algide Cholera," pp. 32, 73.

§ "Cellular Pathology," translated by Dr. Chance, pp. 164, 166, 392.

‖ The term *lymphatic* has been applied to this temperament; by which term was meant a predominance of lymph in the absorbent vessels.

whilst the Fibrin remains the same, a condition of the system which is singularly improved by the remedial employment of Iron;* and, on the other, to Scrofula, in which a diminution of Corpuscles coexists with a deficiency in the amount or in the degree of elaboration of the Fibrin. A similar deficiency in the proportion of Red Corpuscles has been observed by Andral in other cachectic states induced by disease, as in Diabetes Mellitus, Aneurismal dilatation of the Heart producing Dropsy, and in Cachexia Saturnina. It occurs also in Scurvy, and in the advanced stages of Albuminuria; and Dr. Williams† has observed a similar total destruction of the blood-discs in a case of malignant scarlatina with purpura; and has met with indications of a partial destruction of them in acute purpura connected with jaundice, and in cases of functional derangement of the liver.

180. A marked increase in the proportion of the *Colourless Corpuscles* has been frequently observed in the blood of Inflammatory subjects; this increase is not, however, so characteristic of the Inflammatory state as some have supposed; for it is by no means constant in that condition, and is frequently seen in very different states of the system.—Attention has recently been drawn by Prof. J. H. Bennett ‡ to a condition of the Blood, which is especially characterized by a marked excess of these bodies, and which he has designated by the term *Leucocythæmia* (white-cell-blood). This condition has been detected in the blood of a considerable number of individuals suffering under diseases (most commonly enlargement) of the Spleen, Liver, and Lymphatic glands, either separately or in conjunction; but it has not yet been determined how far it is constantly associated with any of these abnormal conditions. In all cases in which such blood has been analyzed, its specific gravity has been found very low, and the total amount of corpuscles small; but the fibrin is almost invariably above the average, having in one instance risen to 7·08.

181. The quantity of *Albumen* in the blood seems to vary less than that of most of its other constituents. The proportion which it bears to

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* The records of Medicine scarcely furnish a more notable example of the pernicious influence of theories founded upon a shallow Empiricism, and of the superiority of a Rational practice based on a knowledge of the real facts of the case, than is afforded by the contrast between the former and the present treatment of *Chlorosis.* Whilst the notion prevailed that the 'buffy coat' is a sign of Inflammation, and that the most potent remedy for Inflammation is loss of blood, patients already reduced to a state of anæmia, who complained of pain in the left hypochondrium, palpitations, &c., were bled over and over again, every withdrawal of blood of course seriously increasing the mischief, by producing a further reduction in the proportion of red corpuscles (§166). The Author well remembers that, when a pupil in the Bristol Infirmary in the years 1833-4, he was repeatedly directed by the estimable Senior Physician (long since dead) to draw eight, ten, or twelve ounces of blood from patients in this condition; and that the crassementum, after coagulation, often resembled a small island floating in an ocean of serum. Yet, because this minute clot exhibited the buffy coat, the bleeding was considered to be 'orthodox' practice, and the obstinacy of the symptoms was attributed to the severity of the disease. If M. Andral had made no other contribution to Medical Science than the demonstration of the real nature of this condition of the blood, and of the influence of further depletion in promoting it, he would have rendered a most essential service to the multitudes of females who are unfortunate enough to suffer from this kind of deterioration of their vital fluid.

† "Principles of Medicine," 2nd edit. p. 115.

‡ See his successive Papers in the "Edinb. Monthly Journal" for 1851, his Treatise "On Leucocythæmia," and his Clin. Lectures "On the Principles and Practice of Med.," 3rd edit., 1859, p. 857 *et seq.*

vein, and both of these differ from the blood of the Jugular. So, again, the blood of the Splenic as well as that of the Renal vein differs from all the preceding. The most important and best-established of these diversities will now be enumerated.—In speaking of the composition of the blood of the *Vena Portæ*, it must be remembered that this consists of two very distinct factors, namely, the blood of the Gastric and Mesenteric veins, and the blood of the Splenic vein; the former having been altered by the introduction of solid and liquid alimentary matters, and the latter by its circulation through the spleen. These, therefore, ought to be separately studied; and this has been done by M. Jules Béclard.* The characters of the blood returning by the *Gastric* and *Mesenteric* veins from the walls of the alimentary canal, are of course affected by the stage of the digestive process, and by the nature and amount of the absorbable matters. As compared with the ordinary venous blood, the total quantity of its solid constituents is lowered during the early part of the digestive process, by the dilution it suffers through the imbibition of liquid; and this diminution is especially remarkable in the corpuscles, the relative proportion of albumen being increased by the introduction of new albuminous matter from the food. Towards the conclusion of the digestive process, however, the blood of the mesenteric veins gradually comes to present the ordinary proportions of these two components; and in an animal that has been subjected to long abstinence, it does not differ from that of the venous system in general. The quantity of extractive is usually increased; and in this part of the blood it must be, that sugar, dextrin, gelatin, and other soluble organic matters that are taken into the circulation, are contained. Some of these have in fact been detected in it.† The fibrin of the blood of the mesenteric veins appears to be less perfectly elaborated than that of the blood in general; for the blood of the mesenteric veins coagulates less firmly (having been erroneously asserted by some not to coagulate at all); and its fibrin, when separated by stirring, shows a marked deficiency in tenacity, and liquefies completely in the course of a few hours. A part of the albuminous constituent of this blood does not present the characters of true albumen, for it is not precipitated by heat or by nitric acid, and the precipitate thrown-down by alcohol is redissolved by water; like albumen, however, it is precipitated by the metallic salts, creosote, and tannin. This substance, which has been distinguished by M. Mialhe as *albuminose*, further differs from true albumen in the facility with which it traverses organic membranes; for these resist the passage of albumen, while they are freely transuded by albuminose. And it is affirmed by M. Mialhe, that the want of that conversion of albuminose into albumen, which ought to take place as part of the assimilating process, is one cause of the readiness with which albuminous matter transudes from the blood in albuminuria and in dropsies; this albuminous matter frequently having rather the characters of albuminose, than those of true albumen.‡

174. That the Spleen ordinarily effects a marked change in the con-

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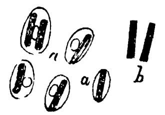
* See his Memoir in the "Arch. Gén. de Méd.," 4^e série, tom. xviii. p. 322 *et seq.*; and his edition of his father's "Elémens d'Anatomie Générale," pp. 265, 266.

† See the Researches of MM. Bouchardat and Sandras in the "Supplément á l'Annuaire de Thérapeutique," 1846.

‡ See the "Cours de Physiologie" of M. Paul Berard, tom. iii. p. 87.

stitution of the blood which passes through it, appears from the analyses made by Mr. Gray and M. Béclard,[*] of the blood drawn from the interior of the organ itself after its removal, the splenic vein having been previously tied. The nature and amount of these changes, however, differ in a very marked degree, according to the stage of the digestive operation and the general condition of the nutritive functions; and it is to this circumstance that we are probably to ascribe much of the diversity in the results obtained by previous experimenters. A marked decrease in the total amount of solid matter is generally observable; the average of twelve experiments giving only 187·1 per 1000 of solid constituents in the splenic blood, whilst the arterial blood of the same animals contained 239 parts, and the jugular venous blood 201 parts. This decrease depends upon the diminished proportion of *red corpuscles*, which seems always to present itself, except in starved or extremely ill-fed animals. On the other hand, the *albumen* usually exhibits a marked increase, which may even double its previous amount; and this seems greatest at an interval of some hours after feeding. The *fibrin* seems to be almost constantly augmented, and this sometimes in a very remarkable degree; the quantity found in the splenic blood varying from 2·5 to 11·53 parts in 1000, or from an amount a little above the usual standard, to nearly six times that average.[†] The blood of the Splenic vein is further remarkable for the large proportion of colourless corpuscles (apparently derived from the white portion of its parenchyma) which it includes. Hirt[‡] counted 1 colourless to 2179 coloured corpuscles in the Blood of the Splenic Artery, but 1 colourless to 60 coloured in that of the Splenic Vein; and the latter is also remarkable for containing a number of fibrinous flakes and of peculiar cells including rod-like crystals of reddish-yellow colouring matter (Fig. 42), which seem to be red corpuscles in a state of degeneration.

FIG. 42.



Blood-corpuscles with rod-like yellow crystals, from Splenic Vein of *Perch*, *a*, blood-cells, treated with water, *b*, free crystals.

175. Many comparative observations have been made upon the blood of the *Vena Portæ* and of the *Hepatic vein*; but a large part of them, according to M. Cl. Bernard, are vitiated by the fact, that, unless the vena portæ be tied, a reflux of blood takes place into it from the liver, so that the blood which flows when it is wounded, is not so much portal as hepatic blood. According to this experimenter, the blood of the hepatic vein is peculiar as containing an increased proportion not only of sugar but also of fat; these substances being generated, during the passage of the blood through the liver, not only from amylaceous or other saccharine matters, but even from azotized compounds. The production of fat is to a certain degree vicarious with that of sugar; and the former

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‖ The term *lymphatic* has been applied to this temperament; by which term was meant a predominance of lymph in the absorbent vessels.

whilst the Fibrin remains the same, a condition of the system which is singularly improved by the remedial employment of Iron;* and, on the other, to Scrofula, in which a diminution of Corpuscles coexists with a deficiency in the amount or in the degree of elaboration of the Fibrin. A similar deficiency in the proportion of Red Corpuscles has been observed by Andral in other cachectic states induced by disease, as in *Diabetes Mellitus, Aneurismal dilatation of the Heart producing Dropsy*, and in Cachexia Saturnina. It occurs also in Scurvy, and in the advanced stages of Albuminuria; and Dr. Williams† has observed a similar total destruction of the blood-discs in a case of malignant scarlatina with purpura; and has met with indications of a partial destruction of them in acute purpura connected with jaundice, and in cases of functional derangement of the liver.

180. A marked increase in the proportion of the *Colourless Corpuscles* has been frequently observed in the blood of Inflammatory subjects; this increase is not, however, so characteristic of the Inflammatory state as some have supposed; for it is by no means constant in that condition, and is frequently seen in very different states of the system.—Attention has recently been drawn by Prof. J. H. Bennett ‡ to a condition of the Blood, which is especially characterized by a marked excess of these bodies, and which he has designated by the term *Leucocythæmia* (white-cell-blood). This condition has been detected in the blood of a considerable number of individuals suffering under diseases (most commonly enlargement) of the Spleen, Liver, and Lymphatic glands, either separately or in conjunction; but it has not yet been determined how far it is constantly associated with any of these abnormal conditions. In all cases in which such blood has been analyzed, its specific gravity has been found very low, and the total amount of corpuscles small; but the fibrin is almost invariably above the average, having in one instance risen to 7·08.

181. The quantity of *Albumen* in the blood seems to vary less than that of most of its other constituents. The proportion which it bears to

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* The records of Medicine scarcely furnish a more notable example of the pernicious influence of theories founded upon a shallow Empiricism, and of the superiority of a Rational practice based on a knowledge of the real facts of the case, than is afforded by the contrast between the former and the present treatment of *Chlorosis*. Whilst the notion prevailed that the 'buffy coat' is a sign of Inflammation, and that the most potent remedy for Inflammation is loss of blood, patients already reduced to a state of anæmia, who complained of pain in the left hypochondrium, palpitations, &c., were bled over and over again, every withdrawal of blood of course seriously increasing the mischief, by producing a further reduction in the proportion of red corpuscles (§166). The Author well remembers that, when a pupil in the Bristol Infirmary in the years 1833–4, he was repeatedly directed by the estimable Senior Physician (long since dead) to draw eight, ten, or twelve ounces of blood from patients in this condition; and that the crassementum, after coagulation, often resembled a small island floating in an ocean of serum. Yet, because this minute clot exhibited the buffy coat, the bleeding was considered to be 'orthodox' practice, and the obstinacy of the symptoms was attributed to the severity of the disease. If M. Andral had made no other contribution to Medical Science than the demonstration of the real nature of this condition of the blood, and of the influence of further depletion in promoting it, he would have rendered a most essential service to the multitudes of females who are unfortunate enough to suffer from this kind of deterioration of their vital fluid.

† "Principles of Medicine," 2nd edit. p. 115.

‡ See his successive Papers in the "Edinb. Monthly Journal" for 1851, his Treatise "On Leucocythæmia," and his Clin. Lectures "On the Principles and Practice of Med.," 3rd edit., 1859, p. 857 *et seq.*

the water of the serum, is of course elevated by anything which diminishes the latter; and thus we find it high in cholera after profuse discharges of fluid from the intestinal canal, and in other cases in which there has been an unusual drain upon the liquid part of the blood, provided that the albumen do not pass off with it, as sometimes happens. Where some special cause is in operation, which favours the escape of the albumen from the circulating current (as happens in various forms of Albuminuria, but especially in the advanced stage of 'Bright's disease'), the amount of albumen in the serum is reduced below the normal standard. Thus Dr. Christison found the entire solids of the serum to be reduced in some instances to 55 or even 52 parts in 1000, his estimate of their normal amount being 83·4; and he found the specific gravity of the serum to fall as low as 1020 or even 1019, the normal standard being from 1027 to 1031. According to Andral, the diminution in the amount of Albumen in the Serum is exactly proportional to the quantity contained in the Urine.*—The proportion of *fatty* matter in the serum, and especially of the cholesterin, has been found by MM. Becquerel and Rodier to undergo an increase at the commencement of most acute diseases; and they have also observed an increase of fat, and especially of cholesterin, in chronic diseases of the liver, in Bright's disease of the kidney, and in tuberculosis. The quantity of fat in the blood sometimes undergoes such an augmentation, as to give to the serum a constant 'milkiness.' This has been observed by Marcet in a case of diabetes, by Traill in hepatitis, by Christison in dropsy, icterus, and nephritis, by Zanarelli in pneumonia, and by Sion in mammary abscess. In Dr. Sion's case, the blood itself was quite milky; it underwent no coagulation; and only a very small quantity of colouring matter was deposited, when it was allowed to stand. This blood was found by Lecanu to contain 206 parts of solid constituents in 1000; but of these no less than 117 parts were fat, the remainder consisting of albumen (64 parts), and of extractive and salines (25 parts). No fibrin could be found, and the quantity of hæmatoglobulin was inappreciable.* Such a fluid must be considered rather as chyle than as blood; and, in the entire absence of coagulating power, corresponds rather with chyle when first absorbed, than with that which is usually transmitted by the thoracic duct (§ 124).—Little is known with certainty regarding the variations of the *alkaline salts* in the blood in different diseases. The analyses which have been made, however, are considered by Prof. Lehmann† to indicate that in very severe inflammations they are greatly diminished; whilst they are much increased in the acute exanthemata and in typhus, in dysentery, Bright's disease, and all forms of dropsy and hydræmia; and are often doubled in quantity in diseases depending upon malarious influences, such as endemic dysentery, malignant forms of intermittent fever, &c. Although a large quantity of saline matter usually passes-off from the blood in Cholera, yet the proportion of water discharged is so much greater, that, as appears from the analyses of Dr. Garrod, the percentage of salines in the blood is rather increased than diminished.‡ The proportion of *Water* in the blood will of course vary reciprocally with that of the solid constituents; and will be especially augmented when there is a marked diminution in the amount of red corpuscles.

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* A case is related by Andral, under this head, which affords an interesting exemplification of the general facts that have been attained by his investigations. A woman who had been suffering from Erysipelas of the face, and had lost blood both by venesection and by leeches, became the subject of Albuminuria. The blood drawn at this time exhibited a considerable diminution in the proportion of Corpuscles, as well as of Albumen,—a fact which the previous loss of blood fully accounted for. After a short period, during which she had been allowed a fuller diet, another experimental bleeding exhibited an increase in the proportion of Corpuscles. Some time afterwards, when the Albumen had disappeared from the Urine, some more blood was drawn; and it was then observed that the Albumen of the Serum had returned to its due proportion, but that the Corpuscles had again diminished, whilst there was a marked increase in the quantity of Fibrin. This alteration was fully accounted-for by the fact, that, in the interval, several Lymphatic ganglia in the neck had been inflamed and had suppurated; and that the patient had been again placed on very low diet. "Thus," observes Andral, "we were enabled to give a complete explanation of the remarkable oscillations which were presented in the proportion of the different elements of the blood drawn at three different times from the same individual; and thus it is that, the more extended are our inquiries, the more easy does it become to refer to general principles the causes of all those changes in the composition of the blood, which, from the frequency and rapidity with which they occur, seem at first sight to baffle all rules, and to take place, as it were, at random. In the midst of this apparent disorder, there is but the fulfilment of *laws;* and in order to obtain these, it is only necessary to strip the phenomena of their complications, and reduce them to their simplest form."

182. That the Blood is subject to a great variety of other morbid alterations, which are sometimes the causes, and sometimes the results, of Disease, cannot be for a moment doubted. But our knowledge of the nature of these changes is as yet very insufficient. The great amount of attention which is being directed by Chemists and Pathologists to the subject, however, will doubtless ere long produce some important results.—Among the most frequent causes of depravation in the character of this fluid, we must undoubtedly rank the retention, in the Circulating current, of matters which ought to be removed by the Excretory processes. We shall hereafter see, that a total interruption to the excretion of Carbonic Acid by the lungs will occasion death in the course of a very few minutes; and even when only a slight impediment is offered to it, so that the quantity of carbonic acid always contained in arterial blood is augmented to but a small degree, a feeling of discomfort and oppression, increasing with the duration of the interruption, is speedily produced. The results of the retention of the materials of the Biliary and Urinary excretions will be hereafter considered (CHAP. IX.); and at present it will be only remarked, that such retention is a most fertile source of slight disorders of the system, that it is largely concerned in producing many severe diseases, and that, if complete, it will most certainly and rapidly bring about a fatal result.

3. *Of the Vital Properties of the Blood, and its Relations to the Living Organism.*

183. It cannot be doubted that the perfect and regular performance of the various actions to which the Blood is subservient, is dependent upon the admixture of its principal components in their due proportions, and upon its freedom from deleterious matters, whether formed within the

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* This remarkable case is cited in Simon's "Animal Chemistry," vol. i. p. 333, from the "Lancette Française," 1835, No. 49.

† "Physiological Chemistry" (Cavendish Society's ed.), vol. ii. p. 262.

‡ "London Journal of Medicine," May, 1849.

system, or introduced into the circulating current from without. And it is not difficult to see how any considerable alteration which affects its *physical* conditions merely, may thereby produce a most serious disturbance in the regularity of the circulation, and in the functions to which it ministers. Thus it has been shown by the experiments of Poisseuille,* that a certain degree of viscidity is favourable to the motion of liquids through capillary tubes; a thin solution of sugar or gum being found to traverse them more readily than pure water will do. Hence any serious alteration in the proportion of the organic and saline compounds dissolved in the liquor sanguinis, and especially in that of the Fibrin (on which the viscidity of the blood appears chiefly to depend), might be expected to produce obstruction in the capillary circulation, and to favour transudation of the fluid portion of the blood; and the numerous experiments of Magendie (Op. cit.) seem to favour this view, although they are far from manifesting that character for accuracy and discrimination, which would be required to afford an authoritative sanction to it. A much more determinate influence, however, must be exerted upon the Red Corpuscles, by any cause which seriously affects the specific gravity of the liquor sanguinis (§ 145); and the perfect elaboration of the Albuminous constituent of the serum has been shown to be requisite, to prevent it from copiously transuding the membranous walls of the vessels which it traverses (§ 173).—These and other physical and chemical relations of the Blood, however, are quite subordinate to its Vital reactions; and it is into them that we have now to inquire.

184. There are only two constituents of the circulating Blood, which can be considered as being *themselves* endowed with *vital* properties; these are, the Fibrin and the Corpuscles. The remainder of its components can scarcely be looked-upon in any other light than as *chemical* compounds, which are to be rendered subservient to the nutritive and other operations of the living tissues in virtue of *their* vitality, or which have already discharged their duty in the system. Before proceeding, however, to inquire into the nature of the relation of these substances to the 'Life of the Blood,' our attention may be advantageously directed to that remarkable change in the state of the blood when withdrawn from the vessels of the living body, which is commonly known as its 'coagulation.' This term, however, as applied to the blood *en masse*, is quite inappropriate; since, as we shall presently see, the coagulation essentially consists in the passage of the fibrin alone from the soluble to the solidified state; and this component scarcely forms more than one hundredth part of the whole solid matter of the circulating fluid. All the phenomena attendant upon this process, and the conditions by which it is influenced, have been made the subject of very careful study, both by Chemists and Physiologists; but it must be admitted that they throw very little light upon the vital relations of the Blood to the Organism at large; these being only sustained whilst it is circulating in a fluid state, and being interfered-with by anything that favours its passage into the form which it assumes when withdrawn from the body.

185. The *Coagulation of the Blood*, then, consists in the new arrange-

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* See M. Magendie's "Leçons sur les Phénomènes Physiques de la Vie," tom. iv. p. 57.

ment of its constituents, which takes place when it is drawn from the vessels and is left to itself, or when the body itself dies (§ 144). This new arrangement essentially depends upon the passage of the Fibrin from the *soluble* to the *insoluble* state, in which it forms, not an amorphous coagulum, but a network of fibres more or less definitely marked-out; in the meshes of which network are included the Red corpuscles, usually grouped-together in columnar masses resembling piles of money. The Crassamentum or Clot thus formed, gradually acquires a degree of firmness proportioned to the amount of Fibrin which it contains, and to the degree of its elaboration; and it undergoes a progressive contraction, by which the Albuminous, Saline, and Extractive matters, still dissolved in the water, are more or less completely expelled from it, constituting the Serum. This separation will not occur, however, if the coagulation take place in a shallow vessel; nor if the amount of Fibrin should be small, or its vitality low. A homogeneous mass, deficient in firmness, presents itself under such circumstances; though the solid part of this may pass into a state of more complete condensation after the lapse of a certain time.—That the coagulation is due to the Fibrin, and that the Corpuscles do not take any active share in the process, appears from several considerations.* A microscopical examination of the Clot shows, that it has the same texture with Fibrin when coagulating by itself; the Corpuscles clustering-together in the interspaces of the network, and not being uniformly diffused through the whole mass. Their specific gravity being greater than that of the Fibrin, they are usually most abundant at the lower part of the clot; and the upper surface is sometimes nearly colourless, especially when the coagulation has taken place slowly; yet this upper part is much firmer than the lower, showing that the Fibrin alone is the consolidating agent. If, after the complete subsidence of the Corpuscles, a little of the colourless Liquor Sanguinis be skimmed-off, it will undergo complete coagulation, forming a colourless clot; as was long ago shown by Hewson. A curious observation has been made by Bernard, showing that, even during life, the Blood-cells have a natural tendency to gravitate to the lowest part of the fluid. Thus in a Horse, laid on the ground in such a position that its long jugular vein was nearly horizontal, a small opening made in the upper surface allowed the escape only of yellowish serous fluid without red corpuscles, whilst from a similar small opening made at the lowest surface of the vein some very black blood issued. Both portions coagulated; the first, of course, giving a colourless clot; the second, as usual, a dark clot, with a well-marked buffy coat.† The same fact may be experimentally demonstrated, by the use of methods which effect an artificial separation of the Fibrin from the Corpuscles. Thus Muller placed the blood of a Frog, diluted with water (or still better, with a very thin syrup), on a paper filter, when the Liquor Sanguinis, having passed through completely unmixed with the

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[*] It is remarkable that this doctrine, clearly established by the older Physiologists, and especially by Hewson, should ever have been put aside, even temporarily, for the untenable hypothesis that the coagulation of the blood is due to a running-together of its red corpuscles.—For an admirable summary of the history of opinion on this subject, see Mr. Gulliver's Introduction to his Edition of Hewson's works (published by the Sydenham Society).

[†] Bernard, "Leçons," 1859, p. 432.

corpuscles, presented a distinct coagulum; although, from the diluted state of the fluid, this did not possess much consistency. Owing to the more minute size of the Blood-discs of warm-blooded animals, this experiment cannot be so readily performed with their blood. So, again, if fresh-drawn blood be continually stirred with a stick, the Fibrin will adhere to it in strings during its coagulation; and the Red corpuscles will be left suspended in the serum, without the slightest tendency to coagulate. Moreover, if a solution of any salt that has the property of retarding the coagulation (such as carbonate of potash or sulphate of soda), be added to the blood, the Corpuscles will have time to sink to the lower stratum of the fluid before the clot is formed; the greater part of the crassamentum is then entirely colourless, and is found by the microscope to contain few or no red particles. It will be presently shown, however, that the difference of specific gravity is by no means the only cause of the separation of the Corpuscles from the Liquor Sanguinis.

186. That the Coagulation of the Blood is not, as some have supposed, a proof of its death, but is rather an act of vitality, appears evident from the incipient organization which may be detected even in an ordinary clot; and still more from the fact, that, if the effusion of Fibrin take place upon a living surface, its conversion into a fibrous solid is the first act in the production of solid tissues, which become constituents of the living fabric; for it seems absurd to maintain that the Blood *dies*, in order to assume a higher form. That the Blood may itself become organized, like plastic exudations of "coagulable lymph," (a doctrine which, though maintained by Hunter, has been subsequently denied,) seems to have been conclusively proved by the researches of Dr. Zwicky,[*] on the changes occurring in the clots of blood which form in blood-vessels, above the points where they have been tied: for he has traced the successive stages of the metamorphosis of the coagulum into connective tissue, and the formation of vessels in its substance; the whole process taking place exactly as in an inflammatory exudation, and the blood-corpuscles exerting no other influence upon it than that of slightly retarding it. Similar observations have been also made by Mr. Paget.[†]—But further, the fibrillation takes place far more perfectly when the fibrinous fluid is effused on a living surface, than when it is spread-out over dead matter; and thus it happens that fibrinous effusions are much more completely converted into fibrous tissue *within* the living body, and in immediate contact with living tissue, than they ever are when removed from it. A marked difference may be observed in this respect between the *superficial* and the *central* portions of a blood-clot which has been effused in the substance of the living solids; for it is always in the former that the organizing process is most advanced, a firm and distinct fibrous membrane being often found on the exterior of such clots, whilst their interior is soft and amorphous.[‡] Generally speaking, the fibrillation is more perfect, the more slowly it takes place; and the higher the previous

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[*] "Die Metamorphose des Thrombus," Zurich, 1846.

[†] See his 'Lectures on the Processes of Repair and Reproduction,' in the "Medical Gazette" for 1849, vol. xliii. p. 1066; and his "Surgical Pathology," vol. i. pp. 173—180.

[‡] See Dr. G. Burrows, in "Medical Gazette," 1835; and Mr. Prescott Hewett, in "Medico-Chirurg. Trans.," vol. xxviii.

vitalization of the fibrin, the longer is it before it changes its state. Thus the coagulation of sthenic inflammatory blood, which produces a clot of remarkable firmness, is much longer in taking-place than the coagulation of ordinary blood; whilst the coagulation of the blood of cachectic subjects, which takes place very rapidly, is feeble and imperfect. The plastic effusions poured-out from the blood in these two opposite conditions, partake of the character of the blood itself; those of the inflammatory blood of a previously healthy subject being converted into fibrous membranes of considerable firmness, which are subsequently penetrated by blood-vessels, and become regularly-organized tissues; whilst those proceeding from the blood of cachectic subjects frequently undergo a certain degree of organization with great rapidity, but do not go-on to the same perfection, and speedily degenerate.*

187. Instances occasionally present themselves, in which the Blood does not coagulate after death, or coagulates very imperfectly. It was affirmed by Hunter† that no coagulation occurs in the blood of animals hunted to death, or of those killed by lightning, by electric shocks, or by blows upon the epigastrium; and this statement has been generally received upon his authority. It is far, however, from being constantly true; for Mr. Gulliver has collected numerous cases in which coagulation was found to have taken place in the blood of animals killed in each of these modes; in some of them, however, the coagulation was very imperfect.‡ It is not improbable that some of the instances of apparent *absence* of coagulation were really cases of *retarded* coagulation (§ 188); and Dr. Polli goes so far as to maintain, that the complete absence of coagulating power is a phenomenon which has no real existence. He states that he has never met with an instance, in which the blood, when left to itself, and duly protected from external destructive influences, did not coagulate before becoming putrid; and that he has more than once found blood to coagulate, which had been taken in a fluid state from the vessels thirty-six or forty-eight hours after death.§ Still there seems no reasonable doubt that non-coagulation *may* occur, when the blood has been previously subjected to conditions which affect the vitality of its fibrin. Such appears to be the case, for example, when death occurs from Asphyxia, as by hanging, drowning, or breathing of irrespirable gases;‖ and the same has been observed in cases of poisoning by hydrocyanic acid, in which asphyxia was probably the immediate cause of death. In certain diseased states, again, we have seen that the coagulating power seems to be completely deficient (§ 178).

188. The rapidity of Coagulation, and the degree in which the clot solidifies, vary considerably; in general, they are in the inverse proportion to each other. Thus, if a large quantity of blood be withdrawn

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[*] See especially Mr. Dalrymple's Memoirs 'On the rapid organization of Lymph in Cachexia,' in the "Med.-Chir. Trans.," vol. xxiii.; and 'On the early organization of Coagula and mixed fibrinous effusions under certain conditions of the system,' Op. cit. vol. xxvii.

[†] "The Works of John Hunter," edited by James F. Palmer, vol. iii. pp. 34, 114.

[‡] See "Edinb. Med. and Surg. Journ.," Oct. 1848, pp. 367, 418; and his Edition of "Hewson's Works," pp. 20, 21.

[§] "Annali Universali," 1845; and "Ranking's Abstract," vol. ii. p. 337.

[‖] See Dr. J. Davy's "Physiological and Anatomical Researches," vol. ii. p. 192.

from the vessels of an animal at the same time, or within short intervals, the portions that last flow coagulate much more rapidly, but much less firmly, than those first obtained. In blood drawn during Inflammatory states, again, the coagulation is usually slow, but the clot is preternaturally firm; especially at its upper part, where the Buffy coat (§ 193) or colourless stratum of fibrin gradually contracts, and produces the 'cup,' which may be generally considered to indicate a high degree of Inflammation. Although the Blood withdrawn from the body coagulates (except under the peculiar circumstances just stated), whether it be kept at rest or in motion, whether its temperature be high or low, and whether it be excluded from the air, or be admitted to free contact with the atmosphere, yet its coagulation may be accelerated or retarded by variation in these conditions.—If the blood be continually agitated in a bottle, its coagulation is delayed, though it will at last take place in shreds or insulated portions; but that rest is not the cause of its coagulation (as some have supposed), is proved by the fact that, if a portion of blood be included between two ligatures in a living vessel, it will remain fluid for a considerable time;* as it also will when effused into the midst of living tissues, or kept in a state of stagnation in parts affected with inflammation. Thus Mr. Gulliver, besides other instances, mentions a remarkable case witnessed by himself, in which a collection of blood which had been effused in consequence of a bruise on the loins, was found uncoagulated when let-out twenty-eight days afterwards; it measured five ounces, was as liquid as blood just drawn from a vein, and showed the normal characters when examined microscopically; and it coagulated in a cup in less than thirty minutes.† And Mr. Paget mentions that he has known the blood remain fluid in the vessels of an inflamed part, though in a state of complete stagnation, for as long as three days.‡—Again, the coagulation is accelerated by moderate warmth, the natural heat of the body from which the blood is taken appearing to be most favourable to it; but the coagulating power appears to be destroyed by a temperature of about 150°, blood heated to that point remaining permanently fluid.§ On the other hand, the coagulation is retarded by cold; but the coagulating power is not destroyed even by extreme cold; for if blood be frozen immediately that it is drawn, it will coagulate on being thawed.—Moreover it is accelerated by exposure to air, but it is not prevented by complete exclusion from it, as is proved by its taking place in a vacuum, or in a shut sac within the dead body: complete exclusion from the air, however, retards the change; as may be easily shown by causing blood to flow into a vessel containing oil, which will form an impervious coating on its surface, and will occasion the coagulation to take place so slowly, that the red particles have time to subside, and the upper stratum of the clot is colourless.*—The effect of the addition of strong solutions of neutral salts to fresh blood, is usually to retard, and sometimes even to prevent, its coagulation; and the same effect is produced by many vegetable substances, particularly those of the narcotic and sedative class, such as opium, belladonna, aconite, hyoscyamus, digitalis, and tea or coffee in strong infusion.† The action of most of those substances, however, which preserve the fluidity of the blood, only continues during such time as their solutions retain a certain strength; for if they be diluted, coagulation will then take place, although in most cases less perfectly than it would have done at first. There appears to be no limit to the time during which the coagulation may be thus postponed; thus Mr. Gulliver‡ mentions that he has kept horse's blood fluid with nitre for fifty-seven weeks, and that it still readily coagulated when diluted with water.§—It is not so difficult, therefore, as it might otherwise seem, to give credit to the statement of Dr. Polli, that, in a case witnessed by himself, complete coagulation of the blood did not take place until fifteen days after it had been withdrawn from the body; and that fifteen days more elapsed, before putrefaction commenced in it. The upper four-fifths of the clot were colourless, the red corpuscles occupying only the lowest fifth. It is additionally remarkable, that the patient (who was suffering under acute pneumonia) being bled very frequently during the succeeding week, the blood gradually lost its indisposition to coagulate.‖

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* The testimony of all experimenters is in accordance on this point, although they differ as to the length of time that elapses before coagulation commences. Mr. Gulliver states that out of many trials made by him, the coagulation commenced within two hours in only a few instances; more commonly, three, four, or five hours elapsed before any clot was formed; and in one instance, the coagulation was incomplete at the end of twenty-four hours. In all these experiments, the blood coagulated in the course of a few minutes, when withdrawn from the living vessel.—See Mr. Gulliver's edition of "Hewson's Works," p. 23.

† Op. cit. p. 17.

‡ "Lectures on Surgical Pathology," vol. i. p. 310.

§ Gulliver, Op. cit. pp. 4, 5.

189. Neither heat nor Carbonic Acid appear to be evolved, as was formerly supposed, during Coagulation; but a small quantity of Ammonia is undoubtedly liberated, and upon this fact Dr. Richardson¶ has founded his theory of the cause of the Coagulation of the Blood. By numerous and carefully-conducted experiments he has shown that all those circumstances which favour the escape of the volatile alkali, as moderate heat, free exposure to air, and removal of the atmospheric pressure, favour also the coagulation of the Blood; whilst such conditions as retard or prevent the escape of the ammonia, such as cold, increase of atmospheric pressure, retention within the vessels, retard the process. He has shown also that ammonia rapidly escapes in the Halitus of the Blood; and that if the halitus of one portion of blood, or of air containing a small

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* Dr. Babington in "Medico-Chirurgical Transactions," vol. xvi.

† See Dr. J. Davy's "Anatomical and Physiological Researches," vol. ii. pp. 101, 102; and Mr. Prater's "Experimental Inquiries in Chemical Physiology," pp. 59, 63, &c. A copious table of the results of their experiments is given in Mr. Ancell's 'Lectures on the Physiology and Pathology of the Blood,' in the "Lancet" for Dec. 21, 1839.

‡ Mr. Gulliver considers this fact, together with the occurrence of coagulation on the thawing of blood which has been frozen whilst yet fluid, as conclusive against the *vital* character of the act; remarking that if we believe the coagulation to be an effect of life, we must admit that we can freeze and pickle the life (Op. cit. p. 21). No such admission, however, is necessary. We do not freeze and pickle the life; but we simply preserve the vital properties of the substance, by preventing it from undergoing spontaneous change; thus doing the same for the blood, as may be done for seeds, eggs, and even highly-organized bodies, which may be kept in a state of 'dormant vitality' for unlimited periods, by cooling or drying them, or by secluding them from the atmosphere. (See "Princ. of Gen. Physiol.")

§ Op. cit. p. 12.

‖ "Gazzetta Medica di Milano," Genn. 20, 1844; cited in Mr. Paget's 'Report' in "Brit. and For. Med. Rev.," vol. xix. p. 252.

¶ See the "Cause of the Coagulation of the Blood," by B. W. Richardson, being the Astley-Cooper Prize for 1856. Lond. 1858.

percentage of ammonia be transmitted through freshly-drawn blood, the latter will remain fluid for a considerable period; and further, that even when coagulation has occurred, the transmission of air-containing ammonia will effect its reconversion into the fluid state. From these and other considerations Dr. Richardson draws the conclusion, that the cause of the coagulation of the blood is the escape of volatile alkali from the blood, which had previously maintained the fibrin in a fluid state. Notwithstanding the care with which Dr. Richardson's experiments were made, various objections have been adduced against them: thus Lister* has noticed that whilst the blood in the larger arteries and veins is usually found coagulated, it remains fluid for days in the smaller vessels, although they are placed under circumstances apparently more favourable for the escape of the volatile alkali; and again, that if a vessel be injured, either in an amputated limb or in the living body, the blood will coagulate sooner in the injured part, although there is no greater opportunity for the escape of ammonia in the one case than in the other. Lister also painted the vessels of a recently-killed animal with ammonia, and found that coagulation still occurred. Brucke,† again, drew some blood from an animal, and exposed it for 15 min. to the air at 32° F.; then introduced it, while yet fluid, into the fresh heart of the animal, in which it remained fluid for 5½ hours, though all the ammonia originally present had probably escaped. Zimmermann has further stated that blood which has been kept in the fluid state by the addition of ammonia will after some time coagulate, though kept in air-tight vessels; whilst Colin found that coagulation was not retarded, but accelerated, by subjecting the blood to increased pressure, the effect of which would be to prevent the escape of the ammonia. Some other objections have been raised by Dr. Davy, Lister and Colin; but the most important one seems to be the production of a coagulum upon the addition of a little blood in such transudations as those of Hydrocele and of Blisters, where the coagulation appears to be wholly independent of the presence or absence of ammonia; and Dr. Richardson's view can therefore scarcely be accepted as offering a full explanation of this remarkable process.‡

190. The vital condition of the walls of the blood-vessels appears to have an important influence upon the fluidity of the Blood. Thus it has been found by Sir A. Cooper and Mr. Thackrah, that whilst blood enclosed in a *living* vein retained its fluidity for some time (§ 188), blood similarly enclosed in a *dead* vein, the atmosphere being completely excluded, coagulated in a quarter of an hour. Moreover, inflammation of the walls of the blood-vessels (which is a condition of *depressed* vitality, CHAP. VIII.) promotes the coagulation of the blood which they contain; and thus it is, that the trunks both of arteries and veins frequently become choked-up by coagula. And, although there can be no doubt that a large proportion of the loose fibrinous masses found in the heart and large vessels after death, are the result of post-mortem coagulation, yet there is often adequate evidence, derived from the symptoms previously observed, and from the appearances presented by

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* Croonian Lecture in the "Proceedings of the Royal Society for 1863."

† See Henle and Meissner, "Bericht," 1857, p. 231; and 1860, p. 290.

‡ Dr. Richardson's theory is equally unsatisfactory when applied to the phenomena of coagulation frequently observed in vegetable juices.

the coagula themselves, that the coagulation has commenced during life; and in all cases of this kind there has been a marked depression of vital power for some time previous to the final extinction of life. Again, it was found by Schroeder Van der Kolk,[*] that if the substance of the brain and spinal marrow be broken-down, coagulation of the blood takes place whilst it is still moving within the vessels; clots being found in them, even within a few minutes after the operation. Further, that the contact of a dead substance promotes coagulation,[†] even in the living and actively-moving blood, is shown by the experiments of Mr. Simon, who carried a single thread (by means of a very fine needle) transversely through an adjacent artery and vein of a dog, and left it there, so that it might cut the stream, for a period of from twelve to twenty-four hours; the consequence of which was, that a coagulum was formed upon the thread, more or less completely obstructing the vessel. There was, however, a marked difference in the coagula formed within the artery and the vein respectively, which may be attributed to the difference in the quality of the fibrin in the blood of the two vessels, or to the difference in the rate of its motion, or to both causes conjointly; for the thread which traversed the artery usually presented a 'vegetation' on its surface, sometimes as large as a grain of wheat, always of a pyramidal shape, with its base attached to the thread, and its apex down-stream; whilst the venous coagulum was a voluminous black clot, chiefly collected on that side of the thread remotest from the heart.[‡]

191. Again, the contact of dead animal matter with the Blood appears to promote the coagulation of its fibrin in a very remarkable degree; occasioning coagula to form, whilst it is yet actively moving in the vessels of the living body. Thus M. Dupuy found that the injection of cerebral substance into the veins of an animal occasioned its death almost as instantaneously as if prussic acid had been administered; the circulation being rapidly brought to a stand, by the formation of voluminous clots in the heart and large vessels. These experiments were repeated and confirmed by M. de Blainville.[§]—The same effect is produced with still more potency, when the substance injected is rather undergoing degradation, than actually dead; for it then seems to act somewhat after the manner of a ferment, producing a marked diminution in the vitality of the solids and fluids with which it may be brought in contact. Such is

[*] "Comment. de Sanguinis Coagulatione," Groningen, 1820.

[†] For various proofs of which see Lister, 'Croonian Lecture on the Coagulation of the Blood,' in "Lancet" for 1863, vol. ii. p. 179.

[‡] "Lectures on General Pathology," p. 56.—Mr. Simon applies this fact to the explanation of the 'vegetations' which so commonly present themselves upon the valves of the heart, in cases of rheumatic endocarditis; maintaining that they are simple deposits from the fibrin of the blood, which is unusually abundant in this condition. This doctrine can only be substantiated, however, by a careful microscopic examination of these substances; and if they should be proved to have the simple constitution which Mr. Simon imputes to them, the fact will in no degree set aside (as he seems to consider it must do) the existence of endocardial inflammation, but will rather confirm it, since the deposition of fibrin on those particular spots is likely to be specially determined by inflammation of the subjacent membrane.

[§] "Gazette Médicale," 1834, p. 521.—There is no reason to suppose that cerebral substance possesses a more special influence than would be exerted by any other tissue which could be as easily mixed-up with the circulating current. The presence of a piece of flesh or of the clot of blood, as Prof. Buchanan has shown, often suffices to determine the coagulation of fibrin in a solution from which it would not otherwise have separated.

pre-eminently the case with *pus*, as was long ago observed by Hunter, and as Mr. H. Lee has since determined more precisely. It was found by the latter, that healthy blood received into a cup containing some offensive pus, coagulated in *two* minutes; whilst another sample of the same blood, received into a clean vessel of similar size and shape, required *fifteen* minutes for its complete coagulation. When he injected putrid pus into the jugular vein of a living ass, coagulation took place so instantaneously as to produce an immediate obstruction to the current of blood, so that the vessel at once acquired a cord-like character; and in this mode, the pus was usually prevented from finding its way into the general current of the circulation. Whilst it thus remains circumscribed by a coagulum of blood, the pus so introduced seems to produce no other constitutional disturbance than is attributable to the local injury; but if the circumscription should be incomplete, and the pus should be carried into the general circulation, it becomes a source of extensive mischief, determining the formation of abscesses in various parts, and producing a most depressing influence on the system at large.*—The effect of certain animal poisons of a still more potent nature, when introduced into the current of the circulation (as by the bite of venomous serpents), appears to be, like that of a high temperature, the entire *destruction* of the coagulating power of the blood, as well as of the vital endowments of the tissues generally.

192. The proportions of Serum and Clot which present themselves after coagulation, are liable to great variation, independently of the amount of the several ingredients characteristic of each; for the crassamentum may include, not only the fibrin and red corpuscles, but also a large proportion of the serum, entangled (as it were) in its substance. This is particularly the case when the coagulation is rapid; and the clot then expels little or none of it by subsequent contraction. On the other hand, if the coagulation be slow, the particles of fibrin usually seem to become more completely aggregated, the coagulum is denser at first, and its density is greatly increased by subsequent contraction. When a firm fresh clot is removed from the fluid in which it is immersed, its contraction is found to go-on increasing for 24 or even 48 hours, serum being squeezed-out in drops upon its surface; and in order, therefore, to form a correct estimate of the relative proportions of Crassamentum and Serum, the former should be cut into slices, and laid upon bibulous paper, that the latter may escape from it as freely and completely as possible.—According to the experiments of Mr. Thackrah,† coagulation takes place sooner in metallic vessels than in those of glass or earthenware, and the quantity of serum separated is much less; in one instance, the proportion of serum to clot was as 10 to 24½, when the blood coagulated in a glass vessel; whilst a portion of the same blood, coagulating in a pewter vessel, gave only 10 of serum to 175 of clot. The specific gravity of Blood is no measure of its coagulating power; for a high specific gravity may be due to an excess in the amount of corpuscles, which form the heaviest part of the blood; and may be accompanied by a diminution in the quantity of fibrin, which is the coagulating element.

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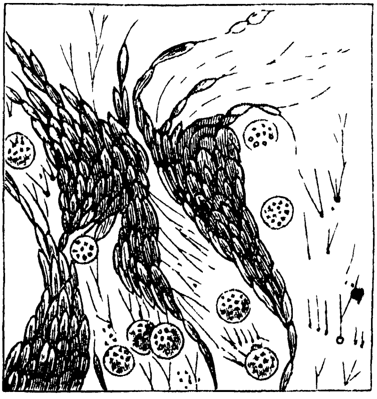
* See Mr. H. Lee's excellent Treatise "On the Origin of Inflammation of the Veins, and on Purulent Deposits."

† "Enquiry into the Nature and Properties of the Blood," 2nd edit., p. 66.

193. The surface of the Crassamentum not unfrequently exhibits, in certain disordered conditions of the blood, a layer that is nearly free from colour; and this is known as the *Buffy Coat.* Its presence has been frequently regarded as a sign of the existence of Inflammation, indicating an undue predominance of fibrin; but this idea is far from being correct, since, as occurs in chlorosis (§ 183), it may result from an opposite condition of the blood. A similar colourless layer is usually observable, when the coagulation of the blood has been retarded by the addition of agents that have the power of delaying it (§ 188); and since, in inflammatory states of the system, the blood is generally long in coagulating, it has been supposed that the separation of the red particles from the fibrinous part of the clot is due to this cause alone. It was long since pointed-out by Dr. Alison,* however, that this explanation is insufficient, for the two following reasons:—"1. The formation of the buffy coat, though no doubt favoured or rendered more complete by slow coagulation, is often observed in cases where the coagulation is more rapid than usual; and the colouring-matter is usually observed to retire from the surface of the fluid in such cases, before any coagulation has commenced. 2. The separation of the fibrin from the colouring-matter in such cases takes place in films of blood, so thin as not to admit of a stratum of the one being laid above the other; they separate from each other laterally, and the films acquire a speckled or mottled appearance, equally characteristic of the state of the blood with the buffy coat itself."—Now we have already seen that the red corpuscles of healthy blood have a tendency to aggregate-together in piles and masses; and it has been pointed-out by Prof. H. Nasse† and Mr. Wharton Jones‡ that this tendency is greatly augmented in inflammatory blood, so that the corpuscles run-together into little clumps often visible to the naked eye, and adhere to each other with considerable tenacity (Fig. 43). Further, it has been shown by Mr. Gulliver,§ that the subsidence of the red corpuscles is more rapid in inflammatory than it is in healthy blood, and that their rate of sinking increases with their aggregation; the addition of weak saline solutions, by which the liquor sanguinis is attenuated, but which diminish the mutual attraction of the red corpuscles, partially or completely preventing the formation of the buffy coat, in blood which exhibited it strongly when left pure, even though its

FIG. 43.



Microscopic appearance of a drop of *Inflammatory Blood;* the *red* corpuscles lose their circular form, and adhere together; the *white* corpuscles remain apart, and are often more abundant than usual.

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* "Outlines of Physiology," 3rd edit., p. 89.

† "Das Blut," cited in Henle's "Anatomie Générale" (trad. par Jourdan), tom. i. p. 468.

‡ 'Report on Inflammation,' in "Brit. and For. Med. Rev.," vol. xvii. p. 567.

§ See his Memoir 'On the Buffy Coat of the Blood,' in the "Edin. Med. and Surg. Journ.," No. 165; and his edition of "Hewson's Works," p. 41.

coagulation was considerably retarded thereby; on the other hand, the addition of mucilage with a small quantity of saline matter, the effect of which is to promote the aggregation of the corpuscles, tended to develope the buffy coat by increasing the rate at which they sink. Now as it has been found that liquor sanguinis deprived of its corpuscles coagulates more slowly than unaltered blood, it does not seem improbable, as Mr. Gulliver has remarked, that this separation of the two components of the crassamentum, which determines the formation of the buffy coat, is partly the cause, rather than the consequence, of the slowness of the coagulation of inflammatory blood.—It is in the buffy coat of inflammatory blood that we see the clearest indications of organization ever presented by the circulating fluid. The fibrous network is frequently extremely distinct; and it commonly includes a large number of colourless corpuscles in its meshes, these, indeed, being sometimes so numerous, that it is almost entirely composed of them. In severe Chlorosis, the buffy coat appears, according to Andral, to be due, not to an increase in the proportion of the fibrin, as in inflammation, but to a diminution in the proportion of Corpuscles, that of the fibrin remaining unchanged.

194. The actual cause of the separation and coagulation of the fibrin is still exceedingly obscure. Dr. Buchanan* remarked that Fibrin might apparently be formed, or at least that coagulation could be induced, by mixing two serous fluids like those of Hydrocele and Ascites, or of Ascites and Pleurisy, neither of which had, separately, any tendency to coagulate: and that coagulation was equally caused by putting into the Serum portions of blood, clot, or of fibrin, either fresh or powdered, muscular fibre, or other tissues. To the same effect are the recent observations of Schmidt,† who attempts to explain the phenomena in question by attributing them to the action of cells, as of the Red or White Corpuscles of the Blood, or of the connective-tissue Corpuscles, upon the fluid: a combination taking place between the albuminous material within the cells (*fibrino-plastic* substance), and the albuminous compound contained in the fluid (*fibrino-genous* substance), both of which he believes he has been able to obtain in a separate state. The influence of Blood Corpuscles in accelerating the coagulation of Chyle and of Blood is undoubted. Their influence on Blood was long since shown by Gulliver.‡ Schmidt found that specimens of Chyle which, under ordinary circumstances, coagulated in from 25 to 90 minutes, on the addition of a little blood, coagulated in from 2 to 3 minutes. He found also that Hæmatoglobulin Crystals possessed the same powers as blood itself. On the other hand, Mr. Gulliver,§ whilst fully admitting and proving experimentally the predisposing agency of cells, insists that they cannot be the efficient cause of the coagulation of Fibrin, not only because the mere admixture of two serous fluids in which no cells are contained will cause the formation of a coagulum, but because certain vegetable juices will coagulate independently of the agency of any cells whatever, and the clot thus obtained will be a kind of mem-

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* "Proceedings of Glasgow Phil. Society," 1845.

† "Müller's Archiv," 1862, p. 543.

‡ Note iv. to "Hewson's Works."

§ Note xviii. to "Hewson's Works;" College Lectures in "Med. T. and Gaz.," Feb. 14, 28, and Oct. 17; and Hunterian Oration, 1863.

branous sac with internal lacunæ, and with its intimate structure composed of fibrils. Brown-Séquard* has made the curious observation, that on injecting defibrinated blood into the separated limbs of animals, fibrin was formed, especially if the muscles were tetanized; and similar results have been obtained by Bernard.† It is remarkable that Splenic Venous Blood, when defibrinated, will, on exposure to the air, form a second coagulum. The Blood returning from the Kidneys and Liver has little or no tendency to coagulate; hence, Brown-Séquard has argued that fibrin is destroyed in these organs, and, from a calculation based on the quantity of blood transmitted through the renal arteries, estimates the total quantity of Fibrin decomposed by the Kidneys alone at from 8 to 10 lbs. per diem.

195. Of the particular purposes which are served by the Fibrin of the blood in the vital economy of the system at large, it must be confessed that we have but little positive knowledge. For putting aside its presumed importance in maintaining that physical condition of the blood which is most favourable to its free movement through the vessels, and to its due retention within their walls (§ 183), we find that it is entirely on the coagulating powers of the blood that the cessation of hæmorrhage from even the most trifling injuries is dependent; that the limitation of purulent effusions by the consolidation of the surrounding tissue, and the safe separation of gangrenous parts, can only take place in virtue of the same property; and that the adhesion of incised wounds, still more the filling-up of breaches of substance, require as their first condition, that either the blood, or matter exuded from it, should be able to assume the state of fibrous tissue. On the other hand, we see the consequences of *excess* of the proportion of fibrin, and of that increased plasticity (or tendency to fibrillate) which usually accompanies its augmentation, in the tendency to form those plastic effusions which are characteristic of the Inflammatory state, and which, if poured-out upon serous or mucous surfaces, constitute 'false membranes' and 'adhesions,' or, if infiltrated into the substance of living tissues, occasion their consolidation. This increased plasticity of the blood, however, may frequently be regarded in the light of an 'effort of Nature' to antagonize the evil consequences of that depression or positive destruction of the vitality of the solid tissues, which seems to form an essential part of the inflammatory condition; and thus it is, that whilst the central part of a mass of tissue, in which the inflammation has been most intense, suffers complete death, and is carried away in the suppurative process, the peripheral part, in which the violence of the inflammation has been less, becomes infiltrated with plastic matter poured-out from the blood, and forms the solid and impermeable wall of the abscess. (See CHAP. VIII. Sect. 3.)

196. Turning now to the Corpuscles of the Blood, we have to inquire into *their* special functions, and into the nature of their participation in the vital operations of the system at large. Here, also, we are obliged to rely upon evidence of a far less satisfactory nature than could be desired; and at whatever conclusions we may arrive, we must hold them as

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* "Journal de la Physiol.," tom. i. p. 299, 1858.

† "Leçons," 1859, vol. i. p. 460.

probable only, and as liable to be modified by further inquiry.—In the first place, upon looking to the chemical constitution of the Red corpuscles, we find that it possesses a remarkable correspondence with that of Muscle, in the proportion of potash-salts which they both contain (in this respect differing in a very marked manner from the liquor sanguinis); whilst their globulin is more nearly related to muscle-substance, than is the fibrin of the blood with which the latter has been usually identified. So, again, it exhibits a like correspondence with that of the Nerve-substance, in the quantity of phosphorized fat which both include (§ 149). Hence we may look upon them as specially subservient to the *vital activity* of the Nervo-Muscular apparatus; since it is one of the most important conditions of that activity, that these tissues shall be supplied with duly-oxygenated blood, and that the carbonic acid which is one of the products of their disintegration, shall be conveyed-away. And this view is in complete harmony with the fact, that the proportion of Red corpuscles in the blood bears a close relation to the amount of Respiratory power (as shown in the quantity of carbonic acid set-free, and in the amount of heat generated) in different classes of Vertebrata; *both* being greatest in Birds, nearly as great in Mammals, very low in most Reptiles, and varying considerably among Fishes.* Again, we observe that among Carnivorous Mammalia, the proportion of red corpuscles is considerably greater than it is among the Herbivorous tribes, whose nervo-muscular energy is (upon the whole) so greatly inferior; and it is in the condition of greatest animal vigour, in the Human system, that we find their amount the greatest, whilst the reduction of that vigour by chronic disease of any description, seems invariably attended with a more marked diminution in this constituent of the blood than in any other. And in those Anæmic states of the system, in which the proportion of red corpuscles is reduced to an extremely low point (§ 179), we invariably find that the animal powers are correspondingly depressed; the capacity for *sustained* exertion, either of the mental faculties, or of the motor apparatus, being almost destroyed, although both the nervous and muscular systems are very easily excited to feeble action.

197. The difficulty of precisely determining the functions of the Red corpuscles, is even surpassed by that of assigning the probable duty of the Colourless. The considerations already adduced appear to show, that the Colourless corpuscles are to be considered as cells of a lower grade than the Red; since they represent them among Invertebrated animals, and also in the incipient blood of Vertebrata; and also, because cells resembling the former (if not the very same) pass-on to develope themselves into the latter. Still we find that this final change does not occur among the Invertebrata; and it is obvious, therefore, that even in their

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* Among Invertebrated animals, as a general rule, the degree of nervo-muscular energy that can be put-forth, the quantity of carbonic acid produced in respiration, and the amount of heat generated in the body, are alike at a low standard; and the fluid constituents of the blood, with the colourless corpuscles that float in it, would seem to convey oxygen to the tissues, and carbonic acid to the respiratory organs, with sufficient facility. In Insects, however, the case is different; their nervo-muscular activity, capacity of respiration, and heat-producing power being all extraordinarily high. Their want of red corpuscles would here seem to be compensated, so far as the respiratory process is concerned, by the introduction of air, through the tracheal apparatus, into the tissues themselves. (See "Princ. of Comp. Phys.," Chap. vi. sect. 3, and Chap. x. sect. 3.)

colourless state, the corpuscles have a function to discharge in the vital economy. The observations of Mr. Newport seem to indicate, that the corpuscles of the blood of Insects (some of them in the condition of 'granule-cells,' others in that of 'nucleated colourless cells'), play an important part in the elaboration of nutrient material. For he found that the 'oat-shaped' corpuscles (the 'granule-cells' of Mr. Wharton Jones) in the Larva, are most numerous at the period immediately preceding each change of skin; at which time the blood is extremely coagulable, and evidently possesses the greatest formative power: whilst the smallest number are met-with soon after the change of skin, when the nutrient matter of the blood has been exhausted in the production of new epidermic tissue.*

198. That condition of the corpuscular element of the blood which is normal in the Insect, must be considered as decidedly abnormal in the Vertebrated animal, in which the circulating fluid goes-on to a higher phase of development; and the excess of Colourless corpuscles in the latter seems always to be associated (save in the early part of life) with an imperfect performance of their nutritive operations. Thus, according to the observations of Mr. Paget,† they are especially abundant in the blood of frogs that are young, sickly, or ill-fed; and as regards the human subject, he confirms the statement of Mr. Wharton Jones and Prof. J. H. Bennett, that the increased proportion of Colourless corpuscles in inflamed blood is most frequent when the subjects of the disease are persons in weak health, or of the tuberculous diathesis. Mr. Paget has also furnished a remarkable confirmation of this view, in the observation, that the inflammatory exudations produced in different individuals, by the application of the same stimulus on the same tissue (*e.g.* by the action of a blister on the skin) are found to present a predominance of the *fibrinous* or of the *corpuscular* element, according to the general condition of the patient.—"The highest health is marked by an exudation containing the most perfect and unmixed fibrin; the lowest by the formation of the most abundant corpuscles, and their nearest approach, even in their early state, to the characters of pus-cells." From such evidence we seem forced to the conclusion, that, whether or not the Colourless corpuscles are to be regarded in any other light than as blood-cells not yet fully developed, their multiplication is *not* the source of increase in the fibrinous constituent of the liquor sanguinis.

199. The fitness of the Blood for circulation through the body is maintained partly by the action of the proper excretory apparatus, and partly by the power which every tissue possesses of withdrawing from the circulating fluid some particular material, or combination of materials, which constitutes its own special *pabulum;* and as the 'pabulum' of each tissue is different, it follows that the normal composition of the blood can only be preserved, without waste of substance, by the existence of such a balance between the appropriative action of the several parts, as shall cause a certain equivalent of blood to supply, without deficiency or surplus, the materials which they collectively require. Such a balance is, in fact, ordinarily preserved; and its maintenance is one of the most marvellous of those exemplifications of Design, which the vital economy of the body presents in no less a degree than its organized

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* "Philosoph. Magazine," May, 1845.

† "Surgical Pathology," vol. i. pp. 313, 314.

structure; an exemplification, however, which becomes yet more marvellous, when it is shown that not only every kind of tissue, but every spot of every organ, has its own special 'pabulum;' drawing something from the blood, which is different from that appropriated by every other part of the body, save the corresponding spot on the opposite side. This position seems fully established by the researches of Dr. W. Budd and of Mr. Paget on 'Symmetrical Diseases'* the phenomena of which are full of interest, as illustrating the ordinary operations of Nutrition. Excluding the cases of congenital symmetrical defects, and a few which seem to depend on morbid influence of the nervous system, it may be stated as a general fact, that all symmetrical diseases depend on the presence of some morbid material in the blood, which usually enters into combination with the tissue that is diseased, or with the organized product of the morbid process. Such a substance fastens upon certain spots or islands on one side of the body, leaving the surrounding parts unaffected; and precisely similar spots or islands are affected in like manner on the other side. The conclusion seems unavoidable, that, however closely one portion of skin or bone may seem to resemble another, the only parts that are *exactly* alike are those which repeat each other symmetrically on the opposite sides of the body; for, although no power of artificial chemistry may determine the difference, the chemistry of the living body makes it evident, the morbid material testing-out the parts for which it has the greatest affinity, uniting with these alone, and passing-by the rest. Thus the syphilitic poison has its 'seats of election' when it begins to attack the bones, fixing upon certain parts of the tibiæ and of the skull with great uniformity; and in the Hunterian Museum are the pelves of two lions, on both of which new osseous deposit has taken place (as the product of some disease resembling rheumatism in man) in a most complex and irregular pattern, this being so similar in the two, that almost every spot and line of the one is represented in the other, with an exactness only inferior to the symmetrical correspondence between the two sides of each.† It has been further pointed-out by Dr. W. Budd, as indicated by the phenomena of these diseases, that next to the parts which are symmetrically placed, none are so nearly identical in composition as those which are analogous, such as the corresponding parts of the superior and inferior extremities.—All these facts tend to demonstrate the perfect and most minute exactness of the adaptation which must exist in the state of health between the blood and all the tissues, as well as the almost inconceivable minuteness of the departure from this adaptation which may become a source of disease; and it is a sure indication of the safety with which we may found such inferences upon them, that the phenomena of symmetrical disease are most distinct, when the disordered action is most conformable, as to its character and its rate, to the normal nutrition of the structure; it being in diseases which (though dependent upon a poison in the blood) are of an inflammatory or other virulent nature, that the symmetry of the morbid change is least obvious. And hence, then, we are led to the conclusion, that, as Treviranus phrased it, "each single part of the body, in respect of its nutrition, stands to

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[*] See their original Essays on this subject in the "Med.-Chir. Trans.," vol. xxv.

[†] See Mr. Paget's 'Lectures on Nutrition, &c.,' in the "Medical Gazette" for 1847, Lect. I.; and his "Lectures on Surgical Pathology," vol. i. pp. 18-23.

the whole body in the relation of an excreted substance;" or, in other words, each part of the body, by taking from the Blood the peculiar substances which it needs for its own nutrition, does thereby act as an excretory organ, inasmuch as it removes from the blood that which, if retained in it, would be injurious to the nutrition of the body generally. Thus, the phosphates which are deposited in our bones, are as effectually excreted from the blood, and as completely prevented from acting injuriously on other tissues, as are those which are discharged with the urine. —The applications of this doctrine have been greatly extended by Mr. Paget,* who has given the following among other examples of its bearing upon the general relations between the blood and the tissues. The hairy covering may be considered to serve, over and above its local purposes, for the removal of certain components of the blood, which would be injurious to its constitution if they remained and accumulated in it; and accordingly we do not find that its development is delayed, until near the period when its protection will be required; for a complete coat (the *lanugo* of the human fœtus) is formed in the fœtus of mammals generally, whilst they are still within the uterus, removed from all those conditions against which hair is a defence; and this coat is shed very soon after birth, being replaced by another of wholly different colour, the growth of which had begun within the uterus. The same principle leads to the apprehension of the true import of the hair which exists in a kind of rudimental state on the general surface of our bodies; and thence to the real meaning of the existence of other organs which permanently remain in a rudimental state, such as the mammary glands of the male. For, as Mr. Paget justly remarks (loc. cit.) "these rudimental organs certainly do not serve, in a lower degree, the same purposes as are served by the homologous parts which are completely developed in other species, or in the other sex. To say they are useless, is contrary to all we know of the absolute perfection and all-pervading purpose of creation; to say they exist merely for the sake of conformity to a general type of structure, is surely unphilosophical, for the law of unity of organic types is, in larger instances, not observed, except when its observance contributes to the advantage of the individual. No: all these rudimental organs must, as they grow, be as excretions serving a definite purpose in the economy, by removing their appropriate materials from the blood, thus leaving it fitter for the nutrition of other parts, or adjusting the balance which might otherwise be disturbed by the formation of some other part. Thus they minister to the self-interest of the individual; while, as if for the sake of wonder, beauty, and perfect order, they are conformed with the great law of unity of organic types, and concur with the universal plan observed in the construction of organic beings."

200. But further, there are many examples in which the presence of a certain substance in the Blood, appears to determine the formation of the particular tissue, of which that substance is the appropriate pabulum. And thus, as the abstraction of the material required for each part leaves the blood in a state fitted for the nutrition of other parts, it seems to follow, as Mr. Paget has further remarked† that such a mutual dependence exists amongst the several parts and organs of the

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* "Lectures on Surgical Pathology," Lect. II.

† Op. cit., p. 32.

body, as causes the evolution of one to supply the conditions requisite for the production of another; and hence, that the order in which the several organs of the body appear in the course of development, while it is conformable to the law of imitation of the parent, and to the law of progressive ascent towards the higher grade of being, is yet the immediate result of changes effected in the condition of the blood by the antecedent operations. And this view is confirmed by many circumstances, which indicate that certain organs really do stand in such a *complemental* relation to one another as it implies; a large class of facts of this order being supplied by the history of the evolution of the generative apparatus, and by that of the concurrent changes in other organs (especially the tegumentary) which are found to be dependent upon it, although there is no direct functional relation between them. Thus, the growth of the beard in man at the period of puberty, is but a type of a much more important change which takes place in many animals with every recurrence of the period of generative activity. It is a matter of common observation, that the deficiency of hair on the face (where this is not, as among the Asiatics, a character of race) is usually concurrent with a low amount of generative power in the male, and may be considered as indicative of it; whilst, on the other hand, the presence of hair on the upper lip and chin of the female is indicative of a tendency in the general organization and mental character towards the attributes of the male, and of a deficiency in those which are typical of the female. If, moreover, the development of the male organs be prevented, the evolution of the beard does not take place; whilst the cessation or the absence of activity in the female organs is often attended by a strong growth of hair on the face, as well as by other changes that may be attributed to the presence of some special nutritive material in the blood, for which there is no longer any other demand. This, again, shows itself yet more strongly in Birds; among which (as Hunter long since pointed-out*) it is no uncommon occurrence for the female, after ceasing to lay, to assume the plumage of the male, and even to acquire other characteristic parts, as the spurs in the fowl tribe. Moreover, it has been ascertained by the experiments of Sir Philip Egerton, that if a buck be castrated while his antlers are growing and are still covered with the 'velvet,' their growth is checked, they remain as if truncated, and irregular nodules of bone project from their surfaces; whilst, if the castration be performed when the antlers are full-grown, these are shed nearly as usual at the end of the season, but in the next season are only replaced by a kind of low conical stumps. That these and similar changes in the development of organs are immediately determined by the condition of the circulating fluid, that is, by the presence or absence of the appropriate 'pabulum' for the parts in question, would further seem likely from the fact, that they may be artificially induced by circumstances which directly affect the condition of the blood. This has been shown by Mr. Yarrell,† in regard to the assumption of the male plumage by the female; and a still more remarkable and satisfactory proof is furnished by the conversion of the 'worker' larva of the Bee into a perfect 'queen,' solely through a change of diet.‡

* 'Account of an Extraordinary Pheasant,' in "Hunter's Works," Palmer's edit., vol. iv. p. 44.

† "Philosophical Transactions," 1827.

‡ "Princ. of Comp. Phys.," § 119.

201. Thus, then, the precise condition of the Blood at any one time, is dependent upon a vast variety of antecedent circumstances, and can scarcely be the same at any two periods of life. Yet we find that, taken as a whole, it exhibits such a remarkable constancy in its leading features, that we can scarcely fail to recognise in it some such capacity for self-development and maintenance, as that which the solid tissues are admitted to possess. And this idea may be thought less strange, when it is borne in mind that the first blood is formed by the liquefaction of the primordial cells of the embryo; and that, notwithstanding the continual change in its components, it still retains its identity through life, in no less a degree than a limb or an eye, the material changes in which, though less rapid, are not less complete. Looking, again, to the undoubted vitality of the Corpuscles, we cannot but perceive that the Life of the Blood is as legitimate a phrase, and ought to carry as much meaning in it, as the Life of a Muscle. And as the one has a period of growth, development, and decline, so must the other.—This view is borne-out, not merely by those palpable differences in the composition of the blood at different ages, which are detectable by our rude methods of examination, but also by those alterations in the tendency to particular constitutional diseases, which at the same time mark the advance of life, and indicate minute and otherwise inappreciable alterations in the circulating fluid. For it is obvious that since the poison of small-pox, for example, less readily produces its characteristic 'zymosis' in the blood of the adult than it does in that of the child, the latter must differ from the former, either in composition or in vital endowments; and that since the tendency to 'fatty degeneration' of the tissues generally, shows itself in a far stronger degree in the aged person than in the adult, this is likely to be in part owing to the condition of the blood, in which, according to the observations of Becquerel and Rodier, there is a decided and progressive increase of cholesterin after the age of 40 or 50 years.

202. Thus, then, we seem justified in the belief that the Blood, like the solid tissues, has a formative power of its own, which it exerts in the appropriation of the new material supplied to it from the food; and that, like all the other parts descended from the component cells of the germinal mass, it goes through a succession of phases, which are partly the cause, and partly the effect, of developmental changes in the organism generally. The self-maintaining power of the Blood is yet more shown in the phenomena of Disease; and especially in its spontaneous recovery of its normal condition, after the most serious perversions; as we see more particularly in febrile diseases of definite type (such, for example, as the Exanthemata, Typhoid, Typhus, &c.), of whose origin in the introduction of specific poisons into the blood, there is no reasonable ground for doubt. In studying the mode in which these and other 'morbid poisons' act upon the blood, and through it upon the system at large, we may derive important assistance from a previous inquiry into the history of the action of those poisonous agents, which, from their being more readily traceable by chemical analysis, can be more satisfactorily made-out. Such an inquiry has a most important bearing, also, on the *modus operandi* of medicines.—The operation of medicinal or poisonous substances for the most part depends upon the power which they possess, when introduced into the current of the circulation, of effecting some determinate change

in the *chemical*, and thereby in the *vital* condition,* either of the components of the blood, or of some one or more of the tissues which it nourishes; and their determination to some special part or organ must be attributed to the same kind of elective affinity, as that by which the normal constituents of the blood are so determined (§ 198). Now, of nearly all these substances it may be said, that the system, if left to itself, tends to free itself from them, provided *time* be allowed for it to do so; and that, when death results from their introduction into it, the fatal result is to be attributed to the fact, that the disorganization of structure and disturbance of function are too rapid and violent to allow the eliminating processes to be set in efficient operation. When smaller doses are taken, their effects are evanescent, unless the abnormal action to which they may have given rise is of a kind to perpetuate itself;† and their cessation is obviously attributable to the removal of the agent from the system, whereby the continuance of its deleterious agency is prevented. Of this removal, we have of course the most satisfactory evidence in the case of those substances which can be detected by ordinary chemical tests in the excretions, such as the alkaline and earthy salts, arsenic, tartarized antimony, and a variety of other metallic compounds, which may readily be detected in the urine for some days after they have been ingested; clearly showing that their elimination is a work of time. On the other hand, the salts of copper appear rather to be removed from the blood by the liver, and also by the bronchial secretion. And lead, which passes-off but little by the ordinary excretions, is withdrawn from the circulation by various tissues and organs, but particularly by certain parts of the muscular apparatus, with the substance of which it becomes incorporated, producing a most injurious influence upon its vital endowments.‡—The only exception to the general rule above stated, seems to be in the case of those medicines which have what is called a 'cumulative' tendency; this tendency being, in fact, simply the result of their want of stimulating influence upon the excretory organs, whose functional activity is rather impeded than promoted by them. This is pre-eminently the case in regard to lead, which is probably the most cumulative poison with which we are acquainted; its continual introduction in doses of even extreme minuteness, being capable, if sufficiently prolonged, of causing the most serious disturbance in almost every function in the economy. Even here, it is rather in the tissues, than in the blood, that it accumulates,—as is indicated by a variety of facts, but more especially by the difficulty with which it is eliminated from the system by means that would be probably effectual in removing it from the circulating current;—and thus we see that, in default of other provision for maintaining the purity of the blood, the whole body (so to speak) acts as an excretory apparatus, and draws into itself the noxious substance.

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* In some instances it has been shown that the action of certain poisons, as Arseniuretted Hydrogen (Gosebruch, Henle and Meissner's "Bericht," 1858, p. 249), effects a physical and perceptible change in the blood, altering the form and colour of its corpuscles, and rendering it unfit for the nutrition of the tissues. Again, Dr. Harley has shown that the addition of strychnia to the blood produces a diminution in the quantity of oxygen which it is capable of absorbing.

† Such a perpetuation is seen in the chronic inflammation, thickening, and contraction, of the œsophageal walls, consequent upon the deglutition of strong acids and caustic alkalies.

‡ This has been shown by the analyses of M. Devergie (see the "Traité des Maladies de Plomb" of M. Tanquerel, tom. ii. pp. 401-6), and of Prof. Miller (see Dr. W. Budd's essay on 'The Symmetry of Disease,' in the "Med.-Chir. Trans.," vol. xxv.).

203. There are numerous cases, moreover, in which poisonous or medicinal substances can be traced in the excretions by chemical tests; their effects, when moderate doses have been taken, passing off so completely, that there can be no doubt of their not being any longer present, as such, in the system. The substances of this class are nevertheless, in many instances, of a nature and composition which render them peculiarly susceptible of change, when subjected to the influences which they must encounter in the living body, and more especially when exposed in a state of very fine division to the agency of oxygen. We see exemplifications of this mode of elimination of poisons in the transient operation of moderate doses of Alcohol, Ether, Chloroform, Opium, Strychnia, Prussic Acid, &c., in all of which the question of life or death is one of *time;* for if the fatal result do not speedily follow the absorption of the poison into the blood, the patient gradually recovers from its effects; and the most effectual treatment consists in the artificial maintenance of the respiratory movements, which the influence of these poisons upon the nervous centres might otherwise suspend. These poisons can frequently, though not always, be detected in the circulating fluid by their sensible or chemical characters, especially if only a short interval has elapsed subsequently to their absorption; thus it has been found by Dr. Lonsdale that the odour of prussic acid cannot be perceived in the blood or in the cavities, when life had been prolonged beyond 15 minutes, although, when death took place within a shorter time, the poison might be detected in the body by its odour alone for eight or nine days afterwards; and the presence of morphia ceases to be recognisable by the ordinary chemical tests, within a short time after it has been taken into the circulating current.—With regard to certain poisons of this unstable class, there is strong evidence that they pass into the urine and are thus eliminated, without undergoing any change that impairs their physiological action; this evidence being afforded in the effects of the re-ingestion of the urine, either by the individuals themselves, or by others. A very curious example of this kind is afforded by the intoxicating fungus, *Amanita muscaria*, which is used by some of the inhabitants of the north-eastern parts of Asia, in the same manner as alcoholic liquors by other nations. Its effects, like those of other excitants, have a limited duration; for a man who is intoxicated by it one day, 'sleeps himself sober' by the next. His restoration is due, however, not to his repose, but to the elimination of the poison which takes place during the interval; for if he drink a cup of his urine the next morning, he is yet more powerfully intoxicated than he was the preceding day; and this fluid has the same effect upon any other individual into whose urine the active principle then passes; so that, according to the testimony of travellers, the intoxicating agent may be transmitted in this manner through five or six persons, a small stock at the commencement thus serving to maintain a week's debauch. Results of the same order have been obtained by Dr. Letheby, in regard to opium, belladonna, hemlock,

aconite, &c.; the passage of these substances into the urine being proved by the induction of their characteristic effects, when that fluid was administered to other animals.

204. Between the substances which admittedly rank as *poisons*, and those which are reckoned as *materies morborum*, no definite line of demarcation can be drawn; and the train of symptoms produced by the operation of the former, is really as much *a disease* as that which results from the presence of the latter. The connection is, in fact, established, by those 'animal poisons' which are the result of decomposition either within or without the body; such as that of the 'pustule maligne,' or of the flesh of animals suffering under disease, on the one hand, or the 'cheese-poison,' 'sausage poison,' &c. on the other.—It may be admitted that our belief in a specific material cause for a great part of the effects set-down to the action of 'morbid poisons,' is merely inferential; and there are many persons to whom their exhibition in a tangible form seems to afford the only convincing evidence of their existence. But it must be remembered that the germs of other ferments constantly exist in the state of suspension in the atmosphere, as is well shown by the experiments of Schröder,* who found that by the mere filtration of air through so coarse a medium as a plug of cotton-wool placed in the mouth of the vessel, was sufficient to prevent the fermentation or putrefaction of almost any organic substance which had been heated to boiling; and it is easy to conceive that pus-cells, or the minute portions of the plasma of various diseases, may be taken up during evaporation and remain long floating in the atmosphere. In the case of those poisons which are capable of being introduced by inoculation, we have, indeed, the required proof of their material existence; and this proof is capable of being extended by a safe analogy to infectious diseases generally. For, if small-pox can be communicated by the inhalation of an atmosphere tainted with the exhalations of a person already affected with it, as well as by the introduction of the fluid of the cutaneous pustule into the blood of another, it can scarcely admit of a question, that the same poisonous agent is transmitted in both cases, although through different media, and that it has as real an existence in the transferred air, as in the transferred pus. Diseases, then, which are capable of being transmitted in both these methods, form the connecting link between those resulting from ordinary toxic agents, and those which must be assumed to depend upon a subtle poison, of which the air alone is the vehicle,—such, for example, as malarious fevers; this assumption being required by all the rules of logic, as the only one which will account for the phenomena to be explained, and therefore possessing a claim to be accepted as an almost certain truth. There is a strongly-marked difference, however, between the *modus operandi* of the toxic agents whose action has been previously examined, and that of the mordid poisons we are now considering; for whilst the former possess a certain definite action, the intensity of which (*cœteris paribus*) is proportionate to the quantity that is in operation, and which is usually determined, in virtue of the 'elective affinity' already spoken-of, to some particular organ or tissue,—the latter act primarily upon the blood, influencing the system at large through the changes which they produce

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* Liebig, "Annalen," cix. heft i.

in its constitution; and their potency depends rather upon the susceptibility of the blood to their peculiar influence, than upon the quantity of the poison that may be introduced into it.

205. Of the existence of such susceptibility, as a 'predisposing cause' of *Zymotic** disease, there cannot be the slightest doubt. In the case of the Exanthemata and Hooping-cough, we see that it is congenital, and is usually removed by the occurrence of one attack of the disease (although this is not a uniform protection); but the liability even to these varies greatly in different individuals, and at different times in the same individual. And with regard to other zymotic diseases, the liability to which is not thus limited, all extended observation concurs in showing that it is augmented by anything which tends to depress the vital powers of the system, and more particularly by any cause which obstructs the due purification of the blood, by the elimination of the products of decomposition. Thus, it will be shown hereafter (CHAP. VII., Sect. 3), that no antecedent condition has been found more efficacious in augmenting the fatality of Cholera, than *overcrowding;* which compels those who are subjected to it, to be constantly breathing an atmosphere not only charged with carbonic acid, but laden with putrescent emanations; and which thus favours the accumulation of decomposing matter in the blood, which serves as the most appropriate soil for the seeds of the disease. And what is true of Cholera has been found to be true of Zymotic diseases in general; the very same fermentible matter in the blood serving for the development of almost any kind of zymotic poison that may be received into the system, whether from the atmosphere, or from the bodies of those who have already been subjects of the disease. That such conditions are constantly present in all large towns is shown in the most satisfactory manner by the observations of Dr. Angus Smith,† who found that whilst on the hills above Manchester the proportion of organic matter was one grain in 200,000 c. i. of air, in the crowded courts of the town there was one grain in every 8000 c. i., indicating but too surely the source of the various diseases of the lungs, brain, and alimentary canal, which the observations of Dr. Greenhow have shown to occur in such excess in town districts,‡ and which probably acts§ by depressing or impairing the functions of the whole body, and particularly of those organs with which it is brought into contact. It is worthy of remark, however, that the effects of the protracted action of this impure air are seen, not so much by any remarkable increase in the relative mortality of the exanthemata in town as compared with country districts, but in the fatal issue which results in the various cases of *nervous diseases;* the proportion of deaths from these being 25·8 in rural, and 38·3 per 1000 in town districts. Hence what has been here spoken of as 'fermentible matter,' is not a mere hypothetical entity, but has a real material existence; for in all those conditions

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* The term *zymotic* is a very convenient designation, which, originally suggested by Dr. W. Farr, has of late gained general currency, for that class of diseases whose phenomena may be attributed to the operation of a morbid poison of the nature described above; this operation bearing a strong analogy to that of 'ferments.'

† "On the Air of Towns."

‡ "Papers on the Sanitary State of the People of England," by G. H. Greenhow, M.D., 1859.

§ "Med.-Chir. Rev.," 1861, vol. ii. p. 441.

of the system in which we know that decomposition is going-on to an unusual extent, and in which there is a marked tendency to putrescence in the excreted matters, we witness such a peculiar liability to zymotic diseases, as clearly indicates that the state of the blood is peculiarly favourable to the action of the zymotic poison. This is pre-eminently the case in the puerperal state, in which the tissue of the uterus is undergoing rapid disintegration, its vital force having been expended; for there is now abundant evidence that the contact of decomposing matters which would be innocuous at other times, is capable of so acting upon the blood of the parturient female, as to induce that most fatal *zymosis* which is known as 'puerperal fever.'* And her peculiar liability is in no respect more manifest than in this; that the poison by which she is affected may have lain dormant for weeks or months, for want of an appropriate nidus, and will yet exhibit its full potency on the very first case in which opportunity may be given for its introduction into the system of a puerperal patient.† The same kind of liability is displayed in the subjects of severe injuries, and in those exhausted by long-continued muscular exertion, among whom, also, there is not only a state of general depression of the vital powers, but also a special source of decomposing matter in the system; for there is evidence that 'surgical fever' may be induced in them, by the introduction of a zymotic poison derived from a variety of external sources (amongst others, from patients affected with puerperal fever), such as would have no effect upon a healthy subject; and, moreover, that overcrowding in hospitals has a special tendency to increase this liability.‡ Thus, then, we may affirm with strong confidence, that the special liability to Zymotic diseases, which determines their *selection* of individuals when epidemically prevalent, depends upon the previous condition of the blood of the subjects who are thus 'predisposed' to their invasion; and more especially on the presence of fermentible matters, resulting from the ordinary processes of disintegration, which, in the state of perfect health, are eliminated as fast as they are formed, but of which an accumulation is prone to take place, either when there are special sources of an augmented production, or when the excretory operations are imperfectly performed.§ And it would further appear, that the continued accumulation of such matters may itself become a source of certain forms of Zymotic disease, which may thus originate *de novo* in the system, and which may thence be propagated to other individuals in some of the modes already specified; of this we have notable examples in hydrophobia, erysipelas, and the 'pustule maligne.'

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* For a most marked and convincing example of this kind, see Dr. Routh's paper on 'The Causes of the Endemic Puerperal Fever of Vienna,' in the "Medico-Chirurgical Transactions," vol. xxxii. p. 27.—That the poison which developes puerperal fever may be conveyed from patients labouring under almost any other form of Zymotic disease tending to putrescence, that is propagable by contact,—such as scarlatina, small-pox, or erysipelas,—is now the general opinion of most pathologists who have paid special attention to the subject.

† This is shown by the instances, unhappily of no unfrequent occurrence, in which practitioners who have unfortunately become the vehicles of the puerperal poison, and have conveyed it to several patients in succession, have experienced the same direful results immediately on resuming obstetric attendance, after a lengthened interval of suspension from it, and even from professional employment of every kind.

‡ See Prof. Simpson 'On the Analogy between Puerperal and Surgical Fever,' in the "Edinb. Monthly Journ.," vol. xi. p. 414; and vol. xiii. p. 72.

§ For a fuller exposition of this doctrine, see the "Brit. and For. Med.-Chir. Rev.," vol. xii. p. 159 *et seq.*

206. It is not only, however, in the class of Zymotic diseases, that we seem distinctly able to trace the operation of morbid poisons circulating in the blood; for there are numerous other maladies, of whose origin in a like condition there can be no reasonable doubt; and these are in some respects more closely analogous than the preceding, to the disordered states induced by the introduction of toxic agents. For in those of which we have now to speak, the action is destitute of any analogy to fermentation, and its potency is strictly proportionate, in each case, to the amount of the dose that is in operation. Here, too, we have a connecting link afforded by those disordered states of the system, which depend upon an undue accumulation of poisons normally generated within it, in consequence of some obstacle to their elimination. Thus, the retention of urea or of uric acid, of carbonic acid, biliary matter, lactic acid, or of other substances which are normal products of the waste or disintegration of the body, in the blood, are as true instances of poisoning as if these substances had been directly injected into the blood-vessels; and the evil is of course increased, when (as frequently happens) augmented production is concurrent with imperfect elimination.

207. In all cases, therefore, one of the first questions which the intelligent Practitioner will feel called-upon to decide, is, whether the malady he has to treat originates in the state of the Blood, or in a disorder purely local; and, if he feel justified in referring it to the blood, whether it merely depends upon an alteration in the proportion of its normal constituents, as in plethora and simple anæmia, or whether its phenomena imply the presence of some toxic substance in the circulating fluid.—If the former be his conclusion, he has then to endeavour to rectify the excess or the deficiency, by reducing the former, or by supplying the latter; as when he bleeds and prescribes low diet for Plethora, and employs iron and generous living in Anæmia. But it is his duty to take care that his means are appropriate to his ends; for there can be little doubt that the too-copious venesection which was formerly practised almost indiscriminately in acute inflammations, had a pernicious tendency to postpone the final recovery from them, whilst it had often but a doubtful efficacy in subduing the first violence of the disease. As a general rule it may be stated, that general blood-letting is likely to be rather injurious than beneficial in *toxic* inflammations, in which the vitality of the blood as a whole is decidedly lowered, notwithstanding the large increase in the proportion of fibrin; and to this rule, the results of careful and extended observation have recently shown that Rheumatism is seldom to be considered an exception, notwithstanding that this disease was formerly considered to be one of those in which the efficacy of copious depletion was most undoubted.—In diseases of *toxic* origin, the treatment must be conducted upon principles exactly the same as those by which the practitioner would be guided in his treatment of a case of ordinary poisoning; but as regards the two classes into which it has been shown that these maladies may be divided, a difference must be made in their application.

208. The 'morbid poisons' of our second class (§ 206) are distin-

guished by this, that there is a continual *new generation* of them within the system; and the first indication of treatment, therefore, will be to check their formation, so far as this may be possible. This is the *rationale* of the dietetic and regiminal treatment of the lithic, lactic, and oxalic diatheses, of lepra and psoriasis, of chronic gout and rheumatism, and many other chronic diseases of toxic origin.—Secondly, we should endeavour to destroy or neutralize the poison, if we have any remedies which possess such an action upon it. Perhaps the curative influence of arsenic in some of the chronic skin-diseases, is one of the best examples of this kind; but it must be admitted that such direct 'antidotes' to morbid poisons are very few in number.—Thirdly, where we cannot thus destroy the poison, we must endeavour to moderate its action upon the system; this is the *rationale* of *palliative* treatment of every description, in which the *fons et origo* of the malady is left unchanged.—But fourthly, our main object must be to eliminate the poison from the system as rapidly as possible, by the various channels of excretion; acting upon these by remedies which either increase their activity, or which so alter the condition of the morbific matter as to enable it to be more readily drawn-off. The judgment of the well-informed practitioner, in the treatment of diseases of this class, is more shown in his discriminative selection of the best means of thus aiding the Blood to regain its normal purity, than in any more apparently 'heroic measures'; and a candid review of the most approved systems of treatment, for diseases of the type here alluded-to, will show that the ratio of their efficacy is in accordance with that of their harmony with the above indications.

209. Among the Toxic diseases of the *zymotic* class, in most of which the poison is introduced from without, the course of the morbid phenomena to which this gives-rise is usually more definite and specific, and its duration more limited. There is no source within the body, whence a new supply of the poison is continually arising; and its operation ceases, therefore, as soon as it is entirely eliminated from the system. But there is this peculiarity in the action of many of the poisons in question, that they have the power of multiplying themselves within the body; thus, for example, when small-pox has been communicated by the inoculation of an excessively minute portion of the virus, hundreds or thousands of pustules are generated, each of them charged with a poison equally potent with that from which they originated. It is to this multiplication, that the extension of zymotic diseases, by communication between individuals affected with them and healthy subjects, is chiefly due; and the question of the 'contagion' or 'non-contagion' of any particular disease of this class, is, therefore, essentially that of the multiplication or non-multiplication of the poison in the human body. This multiplication of certain zymotic poisons is a yet stronger point of analogy to the action of 'ferments,' than that which is afforded by the violence of the changes they induce when compared with the amount in operation. Some of these poisons are of such potency, that, in however minute a quantity they are introduced, they will change the whole mass of the blood in a few minutes, and will act indiscriminately on all individuals alike; this is the case, for example, with the venom of serpents. On the other hand, there are many (as already remarked) which seem to require the presence of some special fermentible matter in the blood (§ 205). And between these

might probably be established a regular gradation,—from those most 'pernicious' forms of malarious poison, which derive their potency from the intensity of vegetable decomposition under the influence of a high temperature; or those 'malignant' types of typhoid poison, which owe their special intensity to animal putrescence engendered by filth and overcrowding; both of these attacking a very large proportion of those who are exposed to them,—to those milder forms of zymotic poisons, which, though derived from the same sources with the preceding, act with so much less of uniformity upon different individuals, that we can scarcely fail to recognise, as a 'predisposing cause,' or rather as a necessary concurrent condition, the presence of some readily-decomposable matter in the blood. The long-continued action of these poisons, in their milder forms, seems itself capable of inducing this condition; thus, a healthy person who settles in an aguish country, may remain free from intermittent fever for a considerable time, but his health gradually deteriorates, and at last he becomes the subject of the disease, which would have much earlier attacked him if his blood had been brought into the 'fermentible' state by irregularity of diet, over-exertion, &c.; and the same may be observed in the case of those long exposed to the poison of typhoid or other fevers, which especially locates itself in animal miasmata, if it be not actually engendered by them.

210. In some of the diseases of this class, the change in the qualities of the Blood produced by the introduction of the poison is such as to give it a morbid action on certain organs or tissues only; their phenomena in this respect corresponding with those of ordinary poisons, and of the toxic diseases previously noticed. Such may be said of vaccinia, gonorrhœa, primary syphilis, &c., in which the general functions of the body seem to be disturbed chiefly or solely through the local disorder. It may happen that, even where a specific poison is present in the blood, it may not be potent enough to manifest itself in any disordered action, either general or local, until the depressed state of the nutrition of some part or organ renders it more susceptible of a further perversion; thus it is very common for the first development of Cancer to follow upon some local injury; and where constitutional Syphilis may be presumed to exist, it often seems to lie dormant, until some appropriate part is rendered, by some such cause, peculiarly susceptible to this malady.*—But, in other cases, we find that the contamination of the blood is such as primarily to produce more or less disturbance in all the functions; as we especially witness in the severer forms of fever, in poisoning by venomous serpents, &c. Even in this last class of cases, however, a special determination to one organ or system is frequently obvious; and this may be so constant as to be characteristic of the disease, as is the case with the skin-affection in the Exanthemata generally, the affection of the throat and the kidneys in Scarlatina, and that of the air-passages in Measles. But in other instances, the local affections produced in different individuals by the same specific poison, vary in their relative intensity, and even in their seat, according to the previous conditions which their respective subjects afford; and whilst, in some instances, this variation may be clearly traced to local peculiarities of nutrition, in others it seems

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* See Mr. Paget's "Lectures on Surgical Pathology," vol. i. p. 492.

only capable of being accounted-for by supposing that the blood of each individual has some peculiar or personal character, which causes it to be differently affected in each subject Of the determining influence of local deteriorations of nutrition, we occasionally meet with curious examples in the Exanthemata thus, the eruption of Measles has been seen to be deepest and most diffused over a knee affected with chronic synovial inflammation and general swelling; and in a patient who became affected with Small-Pox soon after a fall on the nates, the pustules, though thinly scattered elsewhere, were crowded-together on the injured part as thickly as possible * So, during an epidemic Influenza, it is evident that the local affection often manifests itself chiefly (if not solely) in what was previously regarded as the 'weak point' of each patient's system †—The local determination of a morbid poison may frequently be regarded as one of the means whereby the blood and the system at large are freed from its action. Of this, again, we have a most characteristic example in the Exanthemata for it is a matter of constant observation, that the constitutional symptoms, especially fever and delirium, are most severe *before* the cutaneous eruption comes out, that there is much greater danger to life, when the eruption does not develope itself fully; and that its premature repression induces a return of the severer constitutional affection So in Syphilis and Cancer (as Mr Paget remarks), the severest defects or disturbances in the whole economy may coexist with the smallest amounts of specific local disease, and it has been laid-down as a general law by Dr Robert Williams, "that when a morbid poison acts with its greatest intensity, and produces its severest forms of disease, fewer traces of organic alterations of structure will be found, than when the disease has been of a milder character "‡

211 In nearly all the Toxic diseases of the zymotic class, there is a natural tendency to the self-elimination of the poison and of the products of its action on the blood, either by the operation of the ordinary excre-

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* Paget, op cit, p 444

† Of those variations, on the other hand, which, as they cannot be thus attributed to purely local causes, must be referred to peculiarities in the general state of the system, and especially of the blood, of each individual, we have a highly characteristic example in the following incident, which fell under the notice of Prof Huxley, when serving as Assistant Surgeon on board H M S Rattlesnake, which had been engaged on a surveying voyage about New Guinea and Australia The crew seem to have acquired a predisposition to disease, by long confinement, exposure to tropical sunshine, unwholesome food, and other unfavourable influences, but no decided malady had shown itself among them, until one of them, after slightly wounding his hand with a beef bone, had suppuration of the axillary lymphatic glands, with which typhoid symptoms and delirium were associated, and which proved fatal A few days after his death, the sailor who washed his clothes had similar symptoms of disease in the axilla, and for four or five months he suffered with sloughing of portions of the cellular tissue of the axilla, arm, and trunk of the same side Near the same time, a third sailor had diffuse inflammation and sloughing in the axilla, and after this, the disease ran in various forms through the ship's company, between thirty and forty of whom were sometimes on the sick list at once Some had diffuse cellular inflammation, some had inflammation of the lymphatic glands of the head, axilla, and lower extremities, one had severe idiopathic erysipelas of the head and neck, another had phlegmonous erysipelas of the hand and arm after an accidental wound, others had low fever with or without enlargement of glands Finally, the disease took the form of mumps, which affected almost everybody on board. The epidemic lasted from May to July (the winter in the southern hemisphere), the ship being at sea during the whole time

‡ "Elements of Medicine," vol i. p 12.

tory organs, or by the peculiar local actions just adverted-to; and this process takes place in many instances with such regularity, that not only the period which it will altogether require, but each of those successive epochs which mark the stages of development and metamorphosis in the poison and in the products of its action, may be almost exactly predicted. There is not, in fact, a more remarkable indication of the 'Life of the Blood,' than is afforded by its extraordinary power of self-recovery, after having undergone the excessive perversion which is consequent upon the introduction of the more potent Zymotic poisons; and every philosophical physician is ready to admit, that it is to this 'vis medicatrix naturæ,' rather than to any remedial agency which it is in his power to apply, that he must look for the restoration of his patient. The very nature of the action of zymotic poisons upon the blood, seems to forbid the expectation of our being able to neutralize or check that action by antidotes; and the objects of treatment wholly lie, therefore, in promoting the elimination of the morbific matters thus engendered, in keeping-under any dangerous excess of local action, and in supporting the system during the continuance of the malady. In a large proportion of zymotic diseases, it is probable that the oxidation of the morbific matter by the aeration of the blood, is the chief means of its removal; and it is accordant with this view, that the encouragement of the respiratory function, both pulmonary and cutaneous, by a pure and cool atmosphere, and by keeping the skin moist (either by the administration of diaphoretic medicines, or by external applications), should be found one of the most efficient means of promoting recovery.* Whilst mild purgatives may be employed with advantage for the same end, in the earlier stages of these diseases, care must be taken that the system be not too much debilitated by their action; and the same caution must be observed with regard to the use of local depletion or counter-irritation, for the purpose of subduing the violence of some local affection. In fact, the general tendency of these diseases to the *adynamic* type seems to indicate that, however beneficial the immediate results of reducing treatment may appear to be, its remote effects are much to be dreaded. And when the results of a large and varied experience are brought together, the Author believes that those will be found most satisfactory, in which the treatment has been *moderately* evacuant, and *early* sustentative.†

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* Dr. Daniell, whose long familiarity with the most pernicious forms of African fever, and with the various modes of treatment which have been put in practice for its cure, gives a most decided preference to the *sudorific* system in vogue among the natives, as having a vast superiority over the venesections, saline purgatives, and large doses of calomel, which most European practitioners have employed. See his "Sketches of the Medical Topography and Native Diseases of the Gulf of Guinea," p. 120.

† On the subject of the latter portion of this section, see the treatise of Dr. Robert Williams on "Morbid Poisons," the "Principles of Medicine" of Dr. Charles J. B. Williams, the "Lectures on General Pathology" by Mr. Simon, and the chapter on 'Specific Diseases' in Mr. Paget's "Lectures on Surgical Pathology," vol. i.

CHAPTER VI.

OF THE CIRCULATION OF THE BLOOD.

1. *Of the Circulation in General.*

212. THE Circulation of nutritive fluid through the body has for its object, on the one part, to convey to every portion of the organism the materials for its growth and renovation, together with the supply of Oxygen which is requisite for its vital actions, (especially for those of the Nervo-Muscular apparatus); and at the same time to carry-off the particles which are set-free by the disintegration or 'waste' of the tissues, and which are to be removed from the body by the Excreting processes. Of these processes, the one most constantly in operation, as well as most necessary for the maintenance of the purity of the blood, is the extrication of Carbonic acid through the Respiratory organs; and this is made subservient to the introduction of Oxygen into the system. In Man, as in other Vertebrated animals, there is a regular and continuous movement of the nutritive fluid through the sanguiferous vessels; and upon the maintenance of this, the activity of all parts of the organism is dependent. In common with Birds and Mammals, again, Man has a Respiratory circulation entirely distinct from the Systemic; all the blood which has returned from the body being transmitted to the lungs, and being brought back to the heart again, before it is sent-forth afresh for the nourishment of the tissues and for the maintenance of their functional activity. The Heart is placed at the junction of these two distinct circulations, which may be likened to the figure 8; and it may be said to be formed by the fusion of two distinct organs, a 'pulmonary' and a 'systemic' heart; for its right and left sides, which are respectively appropriated to these purposes, have no direct communication with each other (in the perfect adult condition, at least), and seem merely brought together for economy of material.* Each system has its own set of Arteries or efferent vessels, and of Veins or afferent trunks; these communicate at their central extremity by the Heart, and at their peripheral extremity by the Capillary vessels, which are nothing else than the minutest ramifications of the two systems, inosculating into a plexus.—Besides the systemic and pulmonary circulations, however, there is another which is no less distinct, although it has not an impelling organ of its own. This is the 'portal' circulation, which is interposed between the venous trunks of the abdominal viscera and the Vena Cava, for the purpose of distributing that blood through the Liver, in which organ its newly-absorbed materials undergo assimilation, whilst its excrementitious matters are separated by the secreting process. The Vena Portæ, which is formed by the convergence of the gastric, intestinal, splenic, and pancreatic veins, subdivides again like an artery, so as to form a capillary plexus which extends through the whole substance of

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* At an early period of fœtal life, as in the permanent state of the Dugong, the heart is so deeply cleft, from the apex towards the base, as almost to give the idea of two separate organs.

the liver; and the Hepatic vein, collecting the blood from this plexus, conveys it into the Vena Cava. Thus the *portal* circulation is grafted (so to speak) upon the *general* circulation, in precisely the same mode as the respiratory circulation is grafted upon it in Mollusca and Crustacea; and if the 'sinus' of the Vena portæ had possessed contractile muscular walls, it would have ranked as the proper heart of the portal system. The really arterial character of the Vena portæ is well shown by comparing it with the Aorta of Fishes; which is formed by the convergence of the branchial veins, and then distributes the blood which it has received from them to the body generally.

213. That the movement of the Blood through the arterial trunks and the capillary tubes, is, in Man, and in other warm-blooded animals, chiefly dependent upon the action of the Heart, there can be no doubt whatever. It can be easily shown by experiment, that if the arterial current be checked, the capillaries will immediately cease almost entirely to deliver the blood into the veins, and the venous circulation will be consequently arrested. And it has also been proved, that the usual force of the Heart is sufficient to propel the blood, not only through the arterial tubes, but through the capillaries, into the veins, since even a less force will serve to propel warm water through the vessels of an animal recently dead.* But there are certain "residual phenomena" even in Man, which clearly indicate that this is not the whole truth, for not only is the general current of blood greatly modified in its passage through the circulating system, but there are many variations in its movement, which, being very limited in their extent, cannot be attributed to any central disturbance, and must therefore be dependent on causes purely local. Hence we are led to perceive that forces existing in the Blood-vessels themselves must have a considerable influence, in producing both general and local modifications of the effects of the Heart's action. There are also indications of the existence of influences in which the blood-vessels do not partake, arising from those changes occurring between the blood and the tissues, that constitute the processes of Nutrition, Secretion, &c. Of the nature of these influences, and of the degree of their operation, the most correct idea may be obtained by examining the phenomena of the Circulation in those beings, in which the moving power is less concentrated than it is in the higher Animals. Thus we find that in Plants and the lowest Animals, as in the earliest embryonic state of the highest, a movement of nutritious fluid takes place through a system of minute passages or channels excavated in the tissues (representing a *capillary* plexus), without any *vis a tergo* derived from an impelling organ. Ascending a little higher in the series, we meet with a system of vascular *trunks*, distributing the blood to these plexuses, and collecting it again from them, and the walls of these trunks are so far endowed with contractility, as to assist, by a sort of peristaltic movement, in the maintenance of the current through them. Still passing upwards, we find this contractility manifesting itself especially in some limited portion or portions of the vascular system, which execute regular movements of contraction and dilatation; and this tendency to concentration is increasingly observed, until the whole movement is subordinated to the action

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* See Dr Williams's "Principles of Medicine," 2nd edit., p 185, *note.*

of a principal propelling organ, the Heart.*—We shall now examine what agency in the Human Circulation may be attributed to the Heart, the Arteries, and the Veins respectively; and what other forces may be fairly presumed to operate in the Capillary circulation.

2. *Action of the Heart.*

214. The Heart is endowed in an eminent degree with the property of *irritability;* by which is meant, the capability of being easily excited to movements of contraction alternating with relaxation. Thus, after the Heart has been removed from the body, and has ceased to contract, a slight irritation will cause it to execute, not one movement only, but a series of alternate contractions and dilatations, gradually diminishing in vigour until they cease. The contraction begins in the part irritated, and then extends to the rest. It appears, however, from Mr. Paget's experiments,† that it is necessary for the propagation of this irritation, that the parts should be connected by muscular tissue, of which a very narrow isthmus will suffice; and that the propagation will not take place, if the connecting isthmus be composed of tendon, even though this be a portion of the auriculo-ventricular ring, which has been supposed by some to be peculiarly efficacious in this conduction. Like the contractility of these muscles, that of the Heart can only be continuously sustained by a supply of arterial blood to its own tissue. This is shown not only by the serious effects produced by disease of the coronary arteries, but also by the experiments of Erichsen‡ and Schiff;§ the former of whom found that ligature of the coronary arteries rapidly produced cessation of the movements of the heart, especially if the cardiac veins were also opened; whilst the latter obtained a local paralysis of either ventricle, according as the artery distributed to the one or the other was tied. The contractility of the Heart is much less speedily lost in cold-blooded animals than in warm-blooded; the heart of the Frog, for instance, will continue to pulsate for as many as 12 hours after its removal from the body, particularly if kept in an atmosphere of Oxygen, though it ceases in a few minutes if immersed in Carbonic acid gas.‖ It has further been shown by Mr. Tod, that the irritability of the heart is of great duration after death in very young animals; which, as was long since demonstrated by Dr. Edwards, agree with the cold-blooded Vertebrata in their power of sustaining life for a lengthened period without oxygen.

215. It is difficult to account for the long continuance of the alternate contractions and relaxations of the muscular parietes of the Heart, after all evident stimuli have ceased to act upon it; and many theories have been offered on the subject, none of which afford an adequate explanation.¶

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* See "Princ. of Comp. Phys.," chap. v.

† "Brit. and For. Med. Review," vol. xxi. p. 551.

‡ "Lond. Med. Gaz.," 1842, vol. ii. p. 561.

§ "Archiv f. Phys. Heilk.," tom. ix.

‖ Castell, "Muller's Archiv," 1854, p. 226.

¶ In the previous editions of this work it was suggested that the rhythmical movements of the Heart might be accounted for by regarding them as an expression of the peculiar vital endowments of its muscular tissue, and that as the ordinary muscles of the body may, under certain conditions, be conceived to contract spontaneously in consequence of being charged with *motility* or motor force engendered by previous acts of

The extraordinary tendency to *rhythmical* action, by which the heart is distinguished from nearly all other muscles, is shown by the fact, that not only do the entire hearts of cold-blooded or of hibernating animals continue to act long after their removal from the body, but even separated portions of them will contract and relax with great regularity for a long time.[*] Thus the auricles will persist in their rhythmical action, when cut-off above the auriculo-ventricular rings; and the apex of the heart will do the same, when separated from the rest of the ventricle. There is strong reason for believing that the contact of the blood itself with the lining membrane of the Heart is, as Haller maintained, the ordinary stimulus inciting it to contract. That the inner surfaces of the cavities of the Heart are provided with sensory nerves, is incidentally shown by an experiment of Bernard,[†] in which the contact of the bulb of a thermometer with the interior of the ventricles immediately increased the number of pulsations. Schiff[‡] and Budge[§] have, moreover, shown that the action of both auricles and ventricles rapidly ceases if they are placed on blotting paper; but that they may be called into action again, either by immersing them in blood, or by dropping a little blood into their cavities. And an ingenious experiment was made by Haller himself, showing that if arrangements are made by which either the right or left side of the Heart remains filled with blood, whilst the other can discharge its contents and remains empty, that side which is stimulated by the presence of the blood continues to beat rhythmically long after the movement of the other has ceased. When the irritability of the heart is nearly exhausted, the usual *rhythm* is often a good deal disturbed, so that the contractions of the auricles and ventricles do not regularly alternate with each other; and one set frequently ceases before the other.

216. In regard to the influence of the Nervous system upon the Heart, there is abundant evidence to show that its movements may be powerfully affected by causes acting either upon the Cerebro-spinal or upon

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nutrition, so the rhythmical movements of the heart might be due to a simple excess of this motility, continually supplied by the nutritive operations, and as constantly discharging itself in contractile action. This view was supported by a reference to cases of muscular action where no nerves are apparent, as in the embryonic Heart at an early period, and the hearts of the lower animals (the Tunicata for instance), and to cases of local cramp and spasm which it was believed could not be fairly attributed to a perverted reflex action of the nervous system. M. Brown-Séquard, again, has attributed the intermittent action of the Heart and other muscles to the presence of venous blood in their capillaries, which he believes to exert a stimulant action on muscular fibre. (See "Experimental Research, &c.," 1853, p. 114; "Comptes Rendus," 1857; and "Journal de la Physiol.," 1858, p. 95 *et seq.*) Dr. Radcliffe, on the other hand, has adduced evidence to the effect that the true stimulus to the contraction of the Uterus, Heart, and other rhythmically acting organs, as well as indeed of all muscular tissue, is the *absence* of oxygenated or arterial blood ("Epilepsy," 3rd edit., p. 20 *et seq.*); whilst Mr. Paget has endeavoured to explain the phenomena by referring them to an intermission in the processes of nutrition ("Croonian Lecture," 1857). None of these theories, however, appear to afford a sufficient explanation of all the facts, and the essential cause of the rhythmical action of the Heart must still remain an unsolved question.

[*] Reid, indeed, was of opinion ("Cyc. of Anat. and Physiology," vol. ii. p. 611), that the rhythmical action of the heart in the frog could continue in the absence of any physical stimulus, for he observed contractions taking place even in vacuo; but his experiments have been repeated on several occasions with different results, the pulsations ceasing on the withdrawal of the air, and commencing again when it was readmitted.

[†] "Leçons sur les Liquides de l'Organisme," 1859, p. 124.

[‡] "Vierordt's Archiv," 1850, p. 34. [§] "Archiv f. Phys. Heilk.," 1846, p. 561.

the Sympathetic system; and whilst, upon the one hand, the energy and force of its contractions may be augmented by stimuli applied to these centres, it appears to be well ascertained that the Pneumogastric nerves, originating in the Medulla oblongata, may be the means of conveying an influence of a precisely contrary nature, serving to inhibit, restrain, or regulate the Cardiac movements. The fact that the Heart will continue to beat after its removal from the body, or after the *gradual* removal of the whole Cerebro-spinal axis, especially if the flow of blood through the Lungs be kept up by artificial respiration,* as well as the existence of anencephalic monsters which possess a regularly-pulsating heart, clearly show that this organ is not exclusively or *essentially dependent* upon the central nervous system for the continuance of its rhythmical action. Its movements under these circumstances must be regarded as automatic, and governed by the Sympathetic ganglia distributed through its substance. On the other hand, the well-known effects of mental emotions and of sudden and severe injuries of either the Sympathetic or Cerebro-spinal system upon the Heart's action, and the observation of v. Bezold that section or paralysis of the cervical portion of the Spinal Cord occasions a marked diminution of the frequency and force of the cardiac pulsations, whilst stimulation of the lower cut surface effects a corresponding increase, prove with equal certainty that its action may be influenced through nervous fibres in connection with those centres. In reference to the influence of the Pneumogastrics upon the Heart, the experiments of MM. Weber, Budge, Schiff, and others,† have shown that its movements may be immediately *arrested* by the transmission of an interrupted current of electricity through one or both of these Nerves. Now in the case of any voluntary muscle, the passage of such a current through the nerves supplying it produces a state of tonic contraction or tetanus; but in the case of the Heart the effect produced is, on the contrary, that of complete relaxation. The cessation in diastole of the rhythmical action is not, however, of long duration; contraction soon recommences, notwithstanding the continued application of the electrical stimulus; though it can again be arrested by passing the interrupted current through a fresh portion of the nerve, situated lower down or nearer to the Heart. Moreover, it has been observed that after section of the Pneumogastrics, the frequency and force of the Heart's action are manifestly increased, as shown by the increased pressure of the Blood in the arteries. The following theory, suggested by A. v. Bezold,‡ will serve to hold these various facts in connection, and will at the same time give an outline of the laborious investigations which have recently been made by him on this subject. The movements of the Heart, according to this observer, appear to be influenced by three systems of Nerves. One of these is seated in the Heart itself, and is represented by the ganglionic nervous apparatus distributed through its substance; under the automatic and rhythmical action of which, even when the Heart has been removed from the body, a relatively considerable number of feeble pulsations can be performed. The cause of the Rhythm is perhaps attributable to continuous excitations originating in the Cardiac ganglia, which, meeting with continuous resistances in the Cardiac nerves, only periodically—that is to say, after overcoming such opposition—act on the muscular tissue. To this local nervous centre two distinct sets of fibres pass, connecting the heart with the central nervous masses. One of these sets reaches the Heart partly through the cervical and partly through the thoracic and lumbar portions of the great Sympathetic cord. The latter fibres originate in the Medulla oblongata, and descending through the cervical and to some extent through the dorsal and lumbar portions of the Spinal cord, emerge at many different points to unite with the Sympathetic nerve. The function of all these fibres consists in conveying an exciting or stimulant influence from the Medulla to the Heart, when that centre is from any cause roused to action. As often as this occurs, the resistance normally present in the Cardiac nerves is more frequently overcome, and the Heart consequently beats more vigorously and with greater rapidity.—The second set of fibres, on the other hand, when incited to action, increase the resistance ordinarily present in the Heart, and run in the Pneumogastric nerve, also originating, in all probability, from the Medulla oblongata. When strongly excited they can increase the amount of resistance to so great an extent, that it becomes superior to the combined influences of the excitory system of the Medulla oblongata, and of the motor system seated in the Heart itself. After a short interval, however, the resistance diminishes, and the successive discharges of the automatic centres can then reach the heart, though after somewhat longer pauses. Both kinds of nervous system, the excitory and the inhibitory, are in connection with the Sensorium, and may be coetaneously excited by Psychical agency.* There is also reason to believe that the depressing effects of *shock* may be exerted no less directly through the Sympathetic than through the Cerebro-spinal system; and that considerable disturbance may ensue from lesions of such parts of it (at least) as are most nearly connected with the heart. For the well-known fact of sudden death not unfrequently resulting from a blow on the epigastric region, especially after a full meal, without any perceptible lesion of the viscera, seems to indicate that a violent impression upon the widely-spread cœliac plexus of Sympathetic nerves (which will be much more extensively communicated to them when the stomach is full, than when it is empty), may cause the immediate cessation of the Heart's action, in the same manner as a severe injury of the Brain or Spinal Cord. And a case has been put on record, in which the heart's pulsations were occasionally checked for an interval of from 4 to 6 beats, its cessation of action giving rise to the most fearful sensations of anxiety, and to acute pain passing up to the head from both sides of the chest,—these symptoms being connected, as appeared on a post-mortem examination, with the pressure of an enlarged bronchial gland upon the great cardiac nerve.[*]

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* See the Experiments of Dr. Wilson Philip, "Experimental Inquiry," &c. p. 56.

† See Weber in "Archives d'Anat. Gén. et de Physiol.," Jan. 1846, and "Wagner's Handwörterbuch," band iii. 2, p. 31; Budge in "Archiv f. Phys. Heilkunde," 1846, v. p. 319; and Schiff in his "Physiologie," 1859, p. 417 *et seq.*

‡ See his "Untersuchungen über die Innervation des Herzens," Leipzig, 1863.

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* In some interesting experiments made with Woorara, v. Bezold found that in the first instance this poison paralyses the inhibitory, then the excitory, and ultimately the automatic nervous centres, though before paralysing the last two it appears to increase their functional activity. A very different view of the relation of the Pneumogastrics to the Cardiac movements is held by Schiff (see his "Physiologie," 1859, pp. 187 and 417), Moleschott ("Journal de la Physiologie," 1862, p. 124), and others. These observers regard the Pneumogastrics as the only, or at least as by far the most important motor nerves of the Heart, whose conductivity, however, is exhausted with extraordinary facility, the nerves being in fact killed by the application of all except the very *feeblest* currents of electricity, whilst these, if applied with due precaution, effect an *augmentation* in the cardiac movements. Schiff admits that he is unable to explain upon this theory the cause of the increased activity of the Heart after section of both Pneumogastrics. M. Brown-Séquard attributes the cessation of the Heart's action on irritation of the Pneumogastrics to a sudden contraction of the minute vessels of the Heart, produced by the excitation of the vasomotor nerves, which he believes to be contained in the Pneumogastric trunks: but this effect can be produced in the Frog, and according to Hyrtl, there are no vessels in the substance of the heart of that animal!

217. When the Heart is exposed in a living animal, and its movements are attentively watched, they are seen to follow each other with great regularity. In an active and vigorous state of the circulation, however, they are so linked together, that it is not easy to distinguish them into periods; both Auricles contracting, and also dilating, simultaneously; and both Ventricles doing the same. The *systole* or contraction of the Ventricles corresponds with the projection of blood into the arteries; whilst the *diastole* or dilatation of the Ventricles coincides with the collapse of the arteries. The contraction of the Ventricles, and that of the Auricles, alternate with one another; each taking place (for the most part, at least,) during the dilatation of the other. The entire period that intervenes between one pulsation and another, is nearly equally divided between the systole and diastole of the Ventricles, but the division is very unequal as regards the Auricles; scarcely more than one-eighth of the whole being occupied in their contraction, and the remainder being taken-up by their dilatation. The following tabular view will perhaps make the relations of the several parts of this series more intelligible:—

	Auricles.	Ventricles.	
$\frac{7}{8}$	Dilatation.	Contraction.	$\frac{1}{2}$
	Continued Dilatation.	First stage of Dilatation.	$\frac{1}{2}$
$\frac{1}{8}$	Contraction.	Second stage of Dilatation.	

"When the Auricle is about to inject the Ventricle, the latter is empty and contracted, with its distal or ventriculo-arterial valves firmly shut down by the pressure of the blood upon their upper surfaces. Immediately upon the contraction of the Auricle, its contained blood passes into (distending and lengthening) the Ventricle; and the force which it transmits not being sufficient to overcome the arterial pressure and weight of blood upon the upper or arterial surface of the semilunar valves, is expended in distending the Ventricle and closing the auriculo-ventricular valve, which then forms one of the walls of the Ventricle. To this succeeds the ventricular contraction: the auriculo-ventricular valve being already closed, now becomes tense, the pressure in the ventricle overcomes that in the artery, and the semilunar valves are raised."[†] During their contraction the form of the Ventricles undergoes a very marked change, the apex of the Heart being drawn up towards its base, and its whole shape becoming much more globular. Contrary to what might be expected, however, the apex, and not the base, is the part which undergoes least change of position during the systole of the Ventricles, and this appears to be due to the circumstance that the upward movement of the apex effected by the shortening of the Ventricles during contraction, is neutralized by the descent of the whole heart occasioned by the elastic recoil of the great vessels springing from the base. Indeed, there is a slight over-compensation, the apex being actually pressed downwards, and its extremity directed backwards and from right to left. When the Ventricles contract they are clearly seen to descend, whilst the pericardial portions of the aorta and pulmonary artery become suddenly greatly elongated and distended —The *impulse* is felt over every part of the Ventricles during their contraction, but most forcibly over their centre The impulse against the ribs is most probably given by the fibres just above the apex The recent experiments of MM Chauveau and Marey,* with a peculiar form of Sphygmograph in which levers of extreme lightness register the undulations of the air contained in elastic sacs applied to the surface of the Heart and Thorax, show clearly the sequence and duration of the movements of the Auricles and Ventricles, and the coincidence of the *impulse* with the contraction of the Ventricles (Fig 44)

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[*] "Müller's Archiv," 1841, heft iii.; and "Brit. and For. Med. Rev.," Oct. 1841.—It may be surmised that in many cases of *angina pectoris,* in which no lesion adequate to account for death could be discovered, some affection of the cardiac plexus might have been traced on more careful examination.

[†] See the instructive papers by Dr. Halford, now Prof. of Physiology at the Univ. of Melbourne, "On the Times and Manner of the Closure of the Auriculo-Ventricular Valves," and "On the Movements and Sounds of the Heart," Lond., 1861.

FIG 44

Tracing obtained by the Sphygmograph of MM Chauveau and Marey

In this tracing *o* represents the short and abrupt contraction of the Auricles which immediately precedes the more energetic and protracted contraction of the Ventricles, represented by the line *v* The line *c* shows the impulse of the Heart to be coincident with the Ventricular contraction

218 The course of the circulating fluid through the Heart, and the action of its different valves, will now be briefly described —The Venous blood, which is returned by the ascending and descending Vena Cava, enters the *right* Auricle during its diastole, on the contraction of which it is propelled through the tricuspid valves into the Ventricle, which thus becomes completely distended The reflux of blood into the veins during the auricular systole, is impeded by the contraction of their own walls, and is limited on the right side by the valves placed at the junction of the jugular and subclavian veins, but these valves are so formed as not to close accurately, especially when the tubes are distended; so that a small amount of reflux usually takes place, and this is much increased when there is any obstruction to the pulmonary circulation. Whilst the *right* Ventricle is contracting upon the blood that has entered it, the *carneæ columnæ*, which contract simultaneously with its proper walls, put the *chordæ tendineæ* upon the stretch, preventing the flaps of the Tricuspid valve from being driven back into the auricular cavity. The blood is now expelled by the ventricular systole into the Pulmonary artery, which it distends, passing freely through its Semilunar valves; but as soon as the *vis a tergo* ceases, and reflux might take place by the elastic recoil of the arterial walls, the valves are filled out by the backward tendency of

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* "Annal des Scien. Nat," 4th ser Zool, tom. xvii. p. 374, and "Mém. de la Soc. de Biol.," Sér iii tom iii pt ii 1862, p 1.

the blood, and completely check the return of any portion of it into the ventricle. The blood, after having circulated through the lungs, returns as Arterial blood, by the Pulmonary Veins, to the *left* Auricle; whence it passes through the Mitral valve into the *left* Ventricle, and thence into the Aorta through its Semilunar valves,—in the same manner with that on the other side, as just described.

219. There are, however, some important differences in the structure and functional actions of the two divisions of the Heart, which should be here adverted-to.—The walls of the *left* Ventricle are considerably thicker than those of the *right;* and its force of contraction is much greater. The following are the comparative results of M. Bizot's measurements,* taking the average of Males from 16 to 79 years:—

	Base.	*Middle.*	*Apex.*
Left Ventricle . . .	$4\frac{1}{2}$ lines	$5\frac{1}{6}$ lines	$3\frac{3}{4}$ lines.
Right Ventricle . .	$1\frac{15}{16}$ lines	$1\frac{3}{8}$ lines	$1\frac{1}{30}$ lines.

In the Female, the average thickness is somewhat less. It will be seen that the point of greatest thickness in the *left* Ventricle is near its middle; while in the *right*, it is nearer the base. The thickness of the former goes-on increasing during all periods of life, from youth to advanced age; whilst that of the latter is nearly stationary. During pregnancy there is an hypertrophy of the left Ventricle to the extent of 1-4th or even 1-3rd of the original thickness of its walls.† The *left* Auricle is somewhat thicker than the *right;* the average thickness of the former being, according to Bouillaud, a line and a half; whilst that of the latter is only a line. In regard to the relative capacities of the right and left cavities, much difference of opinion has prevailed. The *right* Auricle is generally allowed to be somewhat more capacious than the *left;* and the same is commonly taught of the *right* Ventricle. So much fallacy may arise, however, from the peculiar condition of the animal at the moment of death, that this is not easily proved, and is indeed by no means certain.—The average capacity of the cavities may be estimated, in the full-sized Heart, at about four to five ounces.—There is a well-known anatomical difference between the auriculo-ventricular valves on the two sides, which has given rise to the diversity of name; and this seems, from the researches of Mr. King,‡ to be connected with an important functional difference. The Mitral valve closes much more perfectly than the Tricuspid; and the latter is so constructed as to allow of considerable reflux, when the cavities are greatly distended. Many occasional causes tend to produce an accumulation of blood in the venous system, and in the right side of the Heart; thus, any obstruction to the pulmonary circulation, cold, compression of the venous system by muscular action, &c., are known to favour such a condition. This is a state of peculiar danger, from a liability which over-distension of the Ventricular cavity has, to produce a state of muscular paralysis; and in the structure of the Heart itself, there seems to be a provision against it. For, when the ventricle is thus distended, the Tricuspid valves do not close properly; and a reflux of blood is permitted, not only into the Auricle, but also (through the imperfect closure of their valves under the same circumstances) into the large veins. This is proved by the fact, several times observed by Dr. J. Reid in his experiments upon Asphyxia, &c., that when the action of the right ventricle had ceased from over-distension, he could frequently re-excite it, not merely by puncturing its walls, but by making an opening in the jugular vein.* This fact evidently affords an indication of great importance in the treatment of Asphyxia; and it explains the reflux of blood, or *venous pulse*, which is frequently observed in cases of pulmonary disease, and which, according to Mr. King, always exists even in health, though in a less striking degree.

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* "Mém. de la Soc. Médic. d'Observation de Paris," tom. i.

† Larcher, "Comptes Rendus;" Henle and Meissner, 1857, p. 467.

‡ "Guy's Hospital Reports," vol. ii.

220. When the ear is applied over the cardiac region, during the natural movements of the Heart, two successive *sounds* are heard, each pair of which corresponds with one pulsation; there is also an *interval of silence* between each recurrence, and the sound that immediately follows this interval is known as the *first* sound, the other as the *second.* —The *first* sound is dull and prolonged; it is evidently synchronous with the impulse of the Heart against the parietes of the chest, and also with the pulse, as felt near the heart; it must, therefore, be produced during the Ventricular Systole.—The *second* sound, which is short and sharp,† follows so immediately upon the conclusion of the first, that it cannot take place during the auricular systole as some have supposed, but must be assigned to the first stage of the ventricular diastole, when the auricles also are dilating.—With regard to the relative duration of the *two sounds*, and of the *interval*, widely different estimates have been formed. Thus Laennec considered the lengths of the periods of sound and silence to be respectively 3-4ths and 1-4th of the whole interval between one pulse and another; by Dr. Williams, and by Barth and Roger, the relative lengths of these periods have been estimated at 2-3rds and 1-3rd; whilst the recent experiments of Volkmann‡ (made by adjusting two pendulums to vibrate precisely in the two periods) indicate that they are almost precisely equal.

221. The causes of these Sounds, and more especially of the *first*, have been the subjects of much discussion. A number of very distinct actions are taking-place during the period of the production of the latter; and each of these has been separately fixed-on as competent to produce it. Thus we have (1) the impulse of the heart against the parietes of the chest; (2) the contraction of the muscular walls of the ventricles; (3) the rush of blood through the narrowed orifices of the aorta and pulmonary artery; (4) the general molecular collision of the particles of the blood amongst each other, and their friction against the walls of the ventricles; (5) the sudden collision of the stream of blood issuing from the ventricles with the column of blood at rest on the semilunar valves of the aorta and pulmonary artery; and (6) the sudden tension of the valves of the auriculo-ventricular orifices. An experiment made by Dr. Halford permits the first two of the above-mentioned causes to be at once dismissed. A large dog was chloroformed, and the heart being exposed, its movements were maintained by artificial respiration. In this state,

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* "Physiol., Anatom., and Pathol. Researches," chap. iii.

† The difference between these two sounds is well expressed (as Dr. C. J. B. Williams has remarked) by articulating the syllables lubb, dŭp.

‡ "Die Hämodynamik, nach Versuchen," p. 364.

the sounds being plainly audible, the superior and inferior venæ cavæ, and the pulmonary veins were suddenly compressed, so that the current of blood into both ventricles was arrested; "the heart continuing its action, a stethoscope was again applied, when neither first nor second sound was heard; after a short space of time the veins were allowed to pour their contents into both sides of the heart, and both sounds were instantly reproduced. The veins being again compressed, all sound was extinguished, notwithstanding that the heart contracted vigorously." In regard to the third, fourth, and fifth causes, it has been well remarked,* that as regards the third, there is no abrupt contraction of the passages through which the blood flows from ventricles to vessels; and it may be added, that there would be no sound if there were; sound being only produced at that point in a vessel conveying a stream of fluid, when a sudden *enlargement* occurs. In regard to the fourth cause, it is a sufficient answer to this view, that during other periods of the heart's rhythm, such collision produces no sound as in the passage of the blood from the auricles to the ventricles; and in reference to the fifth cause, which has been ably advocated by Dr. Leared, it appears from Dr. Halford's experiments, that at the moment when the systole of the ventricle is about to take place, the active and passive columns of blood, or those below and upon the semilunar valves, are not separated by any space; that there is no propulsion of the blood from a distance against the passive column, but that when the ventricles contract, the fluid pushes open the valves and communicates its force to the column in the vessels, a circumstance which does not appear likely to be accompanied by much if any sound. We are, therefore, reduced to the single cause of the sudden tension of the auriculo-ventricular valves; and this there appears every reason to believe, as has long been held by Dr. Billing† and Dr. Halford, to be the essential cause of the first sound. At the same time it must be admitted that very high authorities have adduced strong evidence in favour of the second and third of the above-mentioned causes; and that these, consequently, may aid in its production.

222. That the *second* sound is produced in the act of closure of the Semilunar valves, is now almost universally admitted; the simple hooking-back one of these valves by a curved needle against the side of the artery, so as to permit a reflux of blood into the ventricle, being sufficient to suppress this sound altogether. Whether it proceeds from the tension of the valves themselves, or from the recoil of the blood against them, or from both causes combined, has not been clearly determined; probably the last is the true account of it.—When the first sound is altered by disease of the semilunar valves, occasioning obstruction to the exit of blood, the second sound also is affected in its character; and if the disease be of such a kind as to prevent these valves from effectually closing, a reflux of blood takes place into the ventricle at the time of its diastole, causing a rushing sound that is analogous to the ordinary first sound, or to some of its modifications. Thus the second sound may come to acquire so completely the character of the first, that it is difficult to distinguish the two in any other way, than by the synchronousness of the first with the heart's stroke and with the pulse in the arteries.‡

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* By a writer in the "Med.-Chir. Rev.," April, 1860, p. 354.

† "Principles of Medicine."

‡ On the subject of the Sounds of the Heart, the various treatises on Auscultation and

223. There seems adequate reason to believe that the whole, or very nearly the whole, of the blood contained in the Ventricles, is discharged from them at each systole; for the left ventricle is very frequently found quite empty after death; and if a transverse section be made through the heart, when in a state of well-marked *rigor mortis* (which may be considered as representing its ordinary state of complete contraction), the ventricular cavity is found to be entirely obliterated.* The total quantity discharged from either ventricle of the Human heart at each systole, is estimated by Valentin at 5·3 oz., by Volkmann at 6·2 oz., and by Vierordt at 6·3 oz.; but these amounts are deduced from calculation of the (supposed) total of the blood, divided by the estimated duration of its passage through the heart, rather than from actual admeasurement. The time occupied by the Blood in making an entire circuit of the body was attempted to be ascertained by Hering,† by introducing prussiate of potass into one part of the system, and drawing blood from another. He states that he detected this salt in blood drawn from one of the jugular veins of the Horse in about 30 seconds after it had been introduced into the other; in which brief space the blood must have been received by the heart, have been transmitted through the lungs, have returned to the heart again, have been sent through the carotid artery, and have traversed its capillaries. These experiments have been fully confirmed by those of Poisseuille,‡ and of Mr. Blake,§ who found that a solution of nitrate of baryta injected into the jugular vein of a horse appeared in the blood of the carotid artery of the opposite side after an interval of 15 seconds. The same inquiry has been pursued, with improved means, by Vierordt.‖ This observer affixed a number of small cups to a drum which was made to rotate at a certain velocity in front of the opened vein; analyses of the contents of the several vessels enabled him to ascertain with great accuracy the moment at which the salt injected made its appearance. In this way he determined the number of seconds occupied by the blood in performing one entire revolution to be, in Squirrels 4·39, in Cats 6·69, in the Hedgehog 7·61, in Rabbits 7·79, in the Dog 16·7, in the Cock 5·17, in the Duck 10·64, and in the Goose 10·86. He estimates the period in Man at 23·1 seconds (during which there are 28 beats of the heart), of which 2 seconds at most are occupied in traversing the larger arteries, 2½ to 3 seconds in passing through the smaller arteries, 3 seconds for the capillaries, and 4 or 5 seconds for the venous system, which numbers must be multiplied by 2 for the two circulations. Moreover, the coincidence between the cessation of the Heart's action, and the diffusion of the salt through the arterial blood, bear a striking correspondence; and it may be hence inferred, that the arrestment of its muscular movement is due to the effect of this agent upon its tissue, when immediately operating upon it, through the capillaries of the coronary artery.—This conclusion is borne-out

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on Diseases of the Heart, by Williams, Blakiston, Hughes, Walshe, Davies, Bellingham, Stokes, Skoda, Barth and Roger, Weber, and others, may be advantageously consulted; see also the account of Hamernjk's investigations in the "Edin. Monthly Journal," Jan., 1849; and those of Kiwisch in the "Brit. and For. Med.-Chir. Rev.," April, 1852.

* Kirkes and Paget's "Handbook of Physiology," 2nd edit., p. 80.

† "Tiedemann's Zeitschrift," vol. iii. p. 85.

‡ "Annal. des Sciences Nat.," 1843, Zool. t. xix. p. 32.

§ "Edin. Med. and Surg. Journal," Oct., 1841.

‖ See his "Physiologie des Menschen," 1861, p. 111.

by a variety of other experiments; which show that the time of the agency of other poisons that suddenly check the heart's action (which is the especial property of *mineral* poisons), nearly coincides, in different animals, with that which is required to convey them into the arterial capillaries. And it seems to derive full confirmation from the fact, that poisons which act locally on other parts, give the first indications of their operation in the same period after they have been introduced into the venous circulation. Thus, in the Horse, the time that is required for the blood to pass from the jugular vein into the capillary terminations of the coronary arteries, is 16 seconds, as is shown by the power of nitrate of potass to arrest the heart's action within that time; and nitrate of strychnia, injected into a vein, gave the first manifestation of its action on the Spinal Cord in precisely the same number of seconds. In the Dog, the heart's action was arrested by the nitrate of potass in 11 or 12 seconds; and the tetanic convulsions occasioned by strychnia also commenced in 12 seconds. In the Fowl, the former period was 6 seconds, and the latter 6½; in the Rabbit, the first was 4, and the other 4½ seconds.—From such experiments, it seems evident that the rapidity of the Circulation is underrated, in any estimate that we found upon the capacity of the Heart, and its number of pulsations in a given time; and it is difficult to see how the two sets of facts are to be reconciled. According to Hering, the rapidity of the circulation diminishes with age; and Vierordt has shown that with increased frequency of the heart's action, there is in general an increased rapidity of the circulation, at least in the higher Vertebrata. Still it by no means follows that an increase in the frequency of the heart's action in a particular animal should be always accompanied by an increased rapidity in the current of the circulation; in point of fact, the experiments of Hering* show that, in the Dog and Horse, when inflammatory or febrile conditions, such as Pericarditis, were set up, a much longer period is occupied in the passage of the blood than before.

224. The *number* of contractions of the Heart in a given time is liable to great variation, within the limits of ordinary health, from several causes; the chief of these are diversities of Age, of Sex, of Stature, of Muscular exertion, of the condition of the Mind, of the state of the Digestive system, and of the Period of the day.

a. Putting aside the other causes of uncertainty, the following table may be regarded as an approximation to the average frequency of the Pulse, at the several *Ages* specified in it, taking equal numbers of Males and Females.

	BEATS PER MINUTE.		BEATS PER MINUTE.
In the fœtus in utero	140 — 150	From the 7th to the 14th year .	80 — 90
Newly-born infant	130 — 140	From the 14th to the 21st year	75 — 85
During the 1st year	115 — 130	From the 21st to the 60th year	70 — 75
During the 2nd year	100 — 115	Old age †	75 — 80
During the 3rd year	95 — 105		

b. The difference caused by *Sex* appears from the inquiries of Dr.

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* "Archiv f. Phys. Heilk.," 1853, t. xii. p. 133.

† The rise in the average frequency of the pulse in very advanced life, contrary to the prevalent notion, has been determined by the observations of Leuret and Mitivié ("De la Fréquence des Pouls chez les Aliénés"), Dr. Pennock ("Amer. Journ. of Med. Sci.," July, 1847), and Prof. Volkmann (Op. cit., p. 427).

Guy,[*] to be such, that the pulse of the adult Female is more frequent than the pulse of the adult Male, at the same mean age, by from 10 to 14 beats in a minute.

c. The influence of *Stature* is affirmed by Volkmann to be tolerably well defined.[†] The pulse being *cæteris paribus* less frequent as the stature is greater; so that if the pulse of a man of 5½ feet high were 70 per minute, that of a man of 6 feet would be 66·7, and that of a man of 5 feet, 73·8.

d. The effect of *Muscular Exertion* in raising the pulse is well known; as is also the fact, which is one exemplification of it, that the pulse varies considerably with the *posture* of the body. The amount of this variation has been made the subject of extensive inquiry by Dr. Guy; and the following are his results. In 100 healthy Males, of the mean age of 27 years, in a state of rest, the difference between standing and sitting was 10 beats, or about 1-8th of the whole number of beats per minute; the difference between sitting and lying was 5 beats, or 1-13th of the whole; and the difference between standing and lying was 15 beats, or 1-5th of the whole. In 50 healthy Females of the same mean age, the difference between standing and sitting was 7 beats, or 1-13th of the whole; that between sitting and lying was 4, or 1-21th of the whole; and that between standing and lying was 11, or 1-8th of the whole. Dr. Ed. Smith has made similar and very extended observations on Adults in Phthisis and on Children in health; and conjoined with them the influence of period of the day. He found in Phthisis, at 8 A.M., the increase, on assuming the sitting and standing postures, was in each case 10 pulsations per minute, but at 4 P.M. it was reduced to 7, and on the whole average there was an increase of 8½ pulsations in each posture. In healthy Children, at 8 A.M., 12 (noon), 5 P.M., and 8 P.M., the increase in the sitting posture was 12:9:7·3:3·5 pulsations, whilst in the standing posture it was 27:14·6:12:10 pulsations per minute: results which seemed to show that the irritability of the Heart, augmented by the rest and quiescence of sleep, undergoes a gradual diminution through the day. In both sexes, the effect produced by *change* of posture increases with the usual frequency of the pulse, whilst the exceptions to the general rule are more numerous, as the pulse is less frequent. The variation is temporarily increased by the muscular effort, involved in the absolute change of the posture; and it is only by the use of a revolving board, by which the position of the body can be altered, without any exertion on the part of the subject of the observation, that correct results can be obtained. That the difference between standing and sitting should be greater than that between sitting and lying, is just what we should expect, when we compare the amount of muscular effort required in the maintenance of the two former positions respectively. It is stated by Lichtenfels and Fröhlich that the alternate contraction and relaxation of any set of muscles has a much greater effect than their simple tonic contraction in increasing the action of the heart.[‡]

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[*] "Guy's Hospital Reports," vol. iii. p. 312; and "Cyclop. of Anat. and Physiol.," vol. iv., Art. 'Pulse.'

[†] With his usual zeal for *formularization*, Volkmann expresses this ratio, as deduced from a large number of observations, by the ratio $p : p' = h'^{\frac{5}{9}} : h^{\frac{5}{9}}$ (p being the rate of the pulse, and h the height of the body); or, in other words, the ratio is that of *the ninth root of the fifth power* of the height.—Surely this is riding a hobby to the death.

[‡] "Denk. d. kais. Akad. d. Wissens. zu Wien," 1852, t. iii. pt. ii. p. 149.

e. The pulse is well known to be much accelerated by *Mental Excitement*, especially by that of the Emotions; it is also quicker during *Digestion.* The ingestion of warm food produces this effect much more quickly than cold; and according to Budge,* whilst animal food raises the frequency of the pulse more quickly than vegetable, the effect of the latter is much greater and more permanent. Lichtenfels and Fröhlich found that, an hour and a half after breakfast, the pulse was 13 beats per minute quicker than before, whilst there was only an increase of 9 beats an hour after dinner. The pulse was less frequent in vegetarians, however, than in those who fed on animal diet, and was probably less energetic. The ingestion of large quantities of water diminished the frequency of the pulse (Bocker). Dr. Ed. Smith ascertained the rate at each hour of the 24 hours for 3 days successively in health, and for six days in Phthisis. He found that it was never stationary, but that there was a progressive increase after a meal and decrease before a meal, so that there were four maxima and four minima daily. The maxima occurred about two hours after a meal, and were the greatest after breakfast and after tea. The day minima immediately preceded the meals, and all were nearly equal. The pulse invariably fell after 9 P.M., so that supper produced but little effect; and the lowest point of the 24 hours was from 3 to 5 A.M. There was an increase in the morning with sunlight. The difference between the maximum of the day and the minimum of the night amounted in health to from 14 to 34 pulsations, and in Phthisis to from 22 to 45 pulsations. The increase from that of the night to the breakfast maximum was, on the average, 27 pulsations in phthisis. There was a considerable increase in children whilst eating. During a fast of 24 hours the variation in the rate was small, but there was an increase during the usual meal hours and an increase at night.

f. The pulse varies also with the *Season*, and Dr. Ed. Smith has shown by daily experiments throughout the year, that the rate of pulsation is greater in the Spring and Summer than in the Winter, both in health and Phthisis. In experiments made upon Frogs, Budge† and Calliburcés found that immersion of the excised Heart or of the hind legs in warm water increased the frequency of the pulse; the same result was obtained after section of the Crural Nerves, or after poisoning by Woorara, showing that it was not effected through the nervous system.

g. Variations in the pressure of the surrounding atmosphere exert a certain, but not very well ascertained influence on the frequency of the Pulse. Alpine travellers are well acquainted with the increased rapidity of the Pulse which occurs on attaining great heights: but this is probably in great measure attributable to the great muscular exertion previously made. Salvatore Tommasi, however, observed an increase of 8 in the number of his pulsations, after a good night's rest in the Alpi di Susa, at an elevation of between 7000 and 8000 feet.‡ Pravaz§ observed diminution in the frequency of the pulse when the subject was placed in an atmosphere three or four times more dense than the air. Vivenot[*] also observed this effect; he noticed also that the number of Respirations and the quantity of perspiration diminished, whilst the Urine was increased. Bucquoy, on the other hand,[†] in an extensive series of observations, made in a diving-bell, in which he remained from two to three hours at a time, found his pulse uniformly quicker under a pressure of from two to three atmospheres, the effect being most marked at first. Thus, at the commencement it was 22 beats faster per min. than in the open air. After 15 min. it was 13 beats, and after two hours 7 beats.[‡]—Perhaps the widest generalization that can be applied to these various facts in relation to the frequency of the Heart's action is that given by Marey, who concludes that the beats of the Heart are proportionately more frequent as the obstacles which have to be overcome by the contraction of the Ventricles are less. This is at least in accordance with what we know of the action of the voluntary muscles, in which the frequency of contraction certainly bears a direct relation to the diminution of the resistance. On this principle we may explain the results of the well-known experiment of Weber, who, on making a full expiration and then holding his breath, found his pulse rapidly diminish in force and frequency, and on one occasion suddenly stop; for here, by the pressure exerted by the walls of the Chest on the Heart and Lungs, a great obstacle is raised to the passage of the blood;[§] and a similar explanation may be given of the effects produced by cold shower-baths, observed by Bence Jones and Dickenson,[||] in which the pulse fell to only 50 in the minute, and subsequently became feeble, intermittent, and even imperceptible. In these experiments the cause of the diminished frequency of the pulse was, no doubt, the great obstacle to the flow of blood produced by the contraction and increased tension of the vessels throughout the body. On the other hand, we may attribute the acceleration which occurs after food, or after violent exertion, or from mental emotion, and that which is constant in the young, to the increased flow of blood taking place in all these cases to the heart, acting upon it as a stimulus.[¶]

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* "Physiologie," 1861, p. 275. † Ibid., p. 272.

‡ "Fisiologia," 1861, p. 244.

§ "Essai sur l'Emploi Médical de l'Air Comprimé," 1850.

3. *Movement of the Blood in the Arteries.*

225. The Blood propelled from the Heart is distributed to the body in

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[*] "Virchow's Archiv," 1860, xix. p. 492.

[†] Canstatt, 1861, p. 109.

[‡] Longet, p. 811, vol. i.

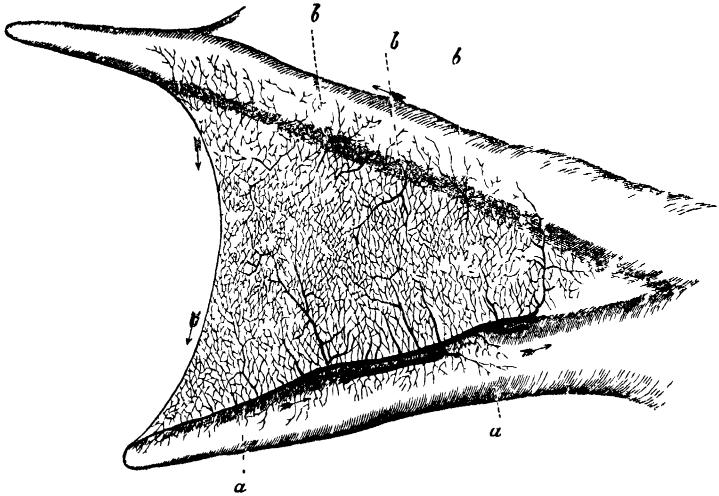
[§] Milne-Edwards, "Leçons sur la Physiologie," vol. iv., 1859, p. 88.

[||] Brown-Séquard, "Journal de la Phys.," 1858, p. 72.

[¶] The channel through which certain poisons affect the Heart is still undetermined. Thus Dybkonsky, Pelikan, and Kölliker found that the poisons of the Upas Antiar, of the Tanghinia venenifera, of Digitalis, and probably also Sulphocyanide of potassium, act as direct paralysers of the muscular fibres of the heart, producing the same effects after as before section of the Pneumogastrics and destruction of the Medulla oblongata ("Mémoires de la Soc. de Biologie," Sér. iii. tom. iii. p. 2). On the other hand, Traube ("Canstatt's Jahresbericht," 1853) found that whilst injection of an infusion of digitalis into the veins of a dog diminished the frequency of the cardiac contractions from 128 to 32 per minute, no such result ensued when the Pneumogastrics were previously divided. And Bernard observed, that whilst nicotine introduced into a wound increased the rapidity of the pulse from 115 to 332 per minute, no effects were produced if the Pneumogastrics were first divided. The influence of smoking has been investigated by Dr. Ed. Smith ("Lancet," March 14, 1863, p. 293), with the result that it soon accelerates the cardiac pulsations; the increase in one instance, between the 13th and 20th minute of smoking, being as much as 31½ pulsations per minute.

general by a system of Arteries, which may be likened in its arrangement to the trunk and branches of a tree, except that very frequent communications or anastomoses exist among these branches, so that, by continual subdivision and inosculation, their distribution comes more and more to resemble the capillary network in which they terminate (Fig. 45).

FIG. 45.



Web of *Frog's foot*, stretching between two toes, magnified 3 diameters; showing the blood-vessels, and their anastomoses:—*a, a,* veins; *b, b, b,* arteries.

Although the *diameters* of the branches, at each subdivision, together exceed that of the trunk, yet there is but little difference in their respective *areas*. What difference does exist, however, is usually in favour of the branches; and thus it happens that there is a gradual increase in the capacity of the arterial system from its centre towards the capillaries, whose capacity is many times greater.—The Arteries exert a most important influence upon the movement of blood through them, in virtue of the physical and vital properties of their walls, or rather of their middle or fibrous coat, which alone is possessed of contractile properties. We find in this coat a layer of yellow Elastic tissue, which is much thicker in the *larger* arteries, in proportion to their size, than in the smaller. On the inside of this is a layer of annular fibres, composed of Muscular fibre-cells, mingled with areolar tissue;* the muscular element, however, is much more abundant in the *smaller* arteries, than in the larger. To the former tissue is due the simple *elasticity* of the arterial walls, which is a physical property that persists after death, until a serious change takes place in their composition; whilst to the latter we are to attribute the property which they unquestionably possess (in common with proper muscular tissue), of *contracting* on the application of a stimulus, so long as their vitality remains. These two endowments are possessed in various degrees, proportional to the respective predominance of the elastic or of the muscular tissue, by the different parts of the Arterial system. Thus, as was justly remarked by Hunter, the *elasticity*, being the property by which the interrupted force of the Heart is made equable and continuous, is most seen in the large vessels more immediately connected with that organ; whilst on the other hand, the *contractility* is most observable in the smaller vessels, where it is more required for regulating the flow of blood towards particular organs.

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* See Prof. Kolliker's "Manual of Human Histology" (Sydenham Society's edit.), vol. ii. p. 291.

226. The Arteries possess a distinct power of contraction, which may be called into play either by the direct application of a stimulus to their walls, or by irritation of the Vaso-motor nerves supplying them. This contractile power is derived from their middle or muscular coat; and it is of course in the smaller arteries that the evidence of its presence should be sought; and this may be readily obtained by observing the effects of various stimuli, mechanical, chemical, or electrical, upon the vessels of a transparent membrane, such as the bat's wing or the frog's foot. Thus if, whilst we watch the movement of blood in a companion artery and vein, we draw the point of a fine needle across them three or four times, without apparently injuring them or the membrane over them, they will both presently contract and close; then, after remaining for a few minutes in the contracted state, they will begin again to dilate, and will gradually increase in diameter until they acquire a larger size than before the stimulus was applied. When in this condition, they will not again contract on the same stimulus as before; the needle may now be drawn across them much oftener and more forcibly, but no contraction ensues, or only a trivial one which is quickly followed by dilatation; with a stronger stimulus, however, such as that of great heat, they will again contract and close, and such contraction may last more than a day, before the vessels again open and permit the flow of blood through them.*—The comparative effects of chemical and other stimuli have been especially studied by Mr. Wharton Jones,† by whom they are thus classified. (1). Constriction may slowly take place, and be slowly succeeded by the normal width; this is the action of the sulphate of atropia. (2). Constriction may quickly take place, and be soon succeeded by the normal width, or a width not much exceeding the normal; this is the result of the moderate application of cold, and of mechanical and galvanic irritation. (3). Constriction either does not take place at all, or when it does, it very rapidly gives place to great dilatation; this is the effect of a weak solution of sulphate of copper, of a strong solution of common salt, of wine, of opium, and of spirit of wine. (4). Dilatation, preceded or not by momentary constriction, may slowly yield to constriction, which remains permanent; this is the effect of sulphate of copper, applied in strong solution, or in substance.—The electric stimulus is most effectual

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* See Mr. Paget's "Lectures on Surgical Pathology," vol. i. pp. 302, 303.—As Mr. Paget justly remarks, it is from the mechanical stimulus of the knife, that small divided vessels contract and close, so as speedily to cease bleeding; but this contraction lasts only for a time; and hæmorrhage would commence on their dilatation, if their mouths were not sealed by coagula of blood or lymph. When secondary hæmorrhage does occur from want of such coagulation, it is most effectually controlled by the application of such stimuli as, like the actual cautery, induce a more prolonged contraction of the vessels.

† 'Prize Essay on Inflammation,' in "Guy's Hospital Reports" for 1850, pp. 8, 9.

when applied by the magneto-galvanic apparatus; and the effects of such application have been investigated by the Professors Weber.* When the minute arteries of the mesentery of frogs, between 1-7th and 1-17th of a Paris line in diameter, were thus stimulated, they did not immediately respond to the irritation, but began to contract after a few seconds, so that their diameter, in from five to ten seconds, was diminished by a third, and their sectional area consequently reduced to about half; by a continued application of the stimulus, their calibre was so much reduced, that only a single row of corpuscles could pass; and at last the vessels became completely closed, and the current of blood arrested, the original conditions being gradually restored on the cessation of the electric current.—Further, it has been ascertained by the careful experiments of Poisseuille (which confirm those of John Hunter), that when an artery is dilated by fluid injected into it, it reacts with a force superior to the distending impulse; and he has also shown that, if a portion of an artery from an animal recently dead (in which the vital contractility seems to be preserved), and one from an animal that has been dead some days (in which nothing but the elasticity remains), be distended with an equal force, the former becomes much more contracted than the latter, after the distending force is removed.

227. Although the walls of the Arteries cannot be readily stimulated to contraction through the medium of their nerves, yet the influence of the Nervous system upon the calibre of the vessels, which might be inferred to exist from the act of blushing and other analogous phenomena, is capable of experimental demonstration. Thus evidence has been afforded by the experiments of Dr. Aug. Waller, that whilst section or ligature of the Sympathetic trunk on either side of the neck produces an enlargement of the minute arteries on that side of the face (as is best seen in the lining of the external ear of the cat or rabbit), accompanied with an elevation of temperature, the application of galvanism to the nerve for a minute or less, causes them to contract to their ordinary calibre.† The branches of nerves which are thus distributed upon the vessels are termed Vaso-motor nerves, and though they appear to be chiefly derived from the Sympathetic system, it seems probable that some vessels are supplied by fibres proceeding from cerebro-spinal nerves and nervous centres. Thus Budge and Waller‡ have shown that irritation of the spinal cord between the second and third cervical vertebræ, occasions a still more powerful contraction of the vessels of the ear than irritation of the Sympathetic itself: an effect which is probably due to an influence conveyed by the great auricular nerve. Budge§ also found that excision of one half of the Spinal Cord between the fifth cervical and the second dorsal vertebræ produced the same effects on the vessels of the head and neck as section of the Sympathetic. Valentin, Schiff, and others, again, have shown that section of the fifth nerve is followed by paralysis and dilatation of the small vessels of the conjunctiva and pituitary membrane; whilst Schiff has observed a similar dilatation of the vessels ramifying on the under

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* "Müller's Archiv," 1847.

† See "Comptes Rendus," 1853, tom. xxxvi. p. 378.—Of this remarkable experiment, which first demonstrated the influence of the Sympathetic Nerve upon the smaller arteries, the Author, by the kindness of Dr. Waller, has himself been a witness.

‡ Ibid.

§ "Physiol.," 1861, p. 289.

side of the tongue to follow section of the Hypoglossals, the effect being still more marked when the linguals were also divided.* The Vaso-motor nerves are capable of being called into action by direct mechanical irritation† and also by reflex action. Callenfels‡, for instance, has noticed contractions of vessels of one ear of a rabbit occur when the opposite ear was pinched; and Brown-Séquard§ observed that on immersion of one hand in cold water, the temperature of the other uniformly fell, in one instance as much as 21° F.: a result which may perhaps serve to explain the effects of the application of cold in controlling hæmorrhage when applied to some distant part of the body. The *permanent* enlargement, however, which is seen in the arteries supplying parts that are in a state of active increase, must be due, not to simple dilatation merely, but to augmented nutrition; since we find that their walls are thickened as well as extended. And, on the other side, when slow contraction occurs in these tubes as a consequence of disease, it must be in part occasioned by atrophy; since their nutrition is so much diminished, that in time they almost entirely disappear,—a portion of a large artery shrivelling into a ligamentous band.

228. Several experiments also indicate the existence of that power of slow contraction in the arteries, which has been distinguished by the appellation *Tonicity*. Thus, when a ligature is placed upon an artery in a living animal, the part of the artery beyond the ligature becomes gradually smaller, and is emptied to a certain degree, if not completely, of the blood it contained. Again, when part of an artery in a living animal is isolated by means of two ligatures, and is punctured, the blood issues from the orifice, and the inclosed portion of the artery is almost completely emptied of its contents. Further, every Surgeon knows, that the contraction of divided arteries is an efficient means of the arrest of hæmorrhage from them, especially when they are of small calibre; so that, in the case of the temporal artery for example, the complete division of the tube is often the readiest means of checking the flow of blood from it, when it has been once wounded. This contraction is much greater than could be accounted-for by the simple *elasticity* of the tissue; and is more decided in small than in large vessels. The empty condition of the arteries, generally found within a short time after death, seems to be in part due to the same cause; since their calibre is usually much diminished, and is sometimes completely obliterated. A remarkable example of the same slow contraction, is that which takes place in the end of the upper portion of an arterial trunk, when the passage of blood through it is interrupted by a ligature; for the current of blood then passes-off by the nearest large lateral branch; and the tube of the artery shrivels, and soon becomes impervious, from the point at which the ligature is applied, back to the origin of that branch. This last fact is important, as proving how little influence the *vis a tergo* possesses over the calibre of arterial tubes; since, without any interruption to the pressure of blood occasioned by it, the tube becomes impervious. It is to the moderate action of the *tonicity* of arteries, that their contraction upon the stream of blood passing through them (which serves to keep the tubes

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[*] "Archiv f. Phys. Heilk.," 1853, p. 377.

[†] See Marey, "Annal. des Sci. Nat.," 1858, t. ix. p. 68.

[‡] "Zeits. f. Rat. Med.," 1855, band vii. p. 191.

[§] "Journ. de la Physiol.," 1858, p. 504.

always full) is due. If the tonicity be excessive, the pulse is hard and wiry; but if it be deficient, the pulse is very compressible, though bounding, and the flow of blood through the arteries is retarded. Dr. C. J. B. Williams has performed some ingenious experiments (§ 253), which prove that the force required to propel fluid through a tube whose sides are yielding, is very much greater than that which will carry it through a tube of even smaller size with rigid parietes; consequently a loss of tonicity in the blood-vessels retards the flow of blood through them; whilst an increase hastens it.—There is much less difference between the Irritability and the Tonicity of arteries, than between the like properties in ordinary muscle; since the former is so long in manifesting itself, that it almost approaches to the character of the latter. But in the Arteries, as in other muscles, the *tonic* contraction may be most efficiently induced by *cold.* Thus Hunter observed that the exposure of an artery of a warm-blooded animal to the air for some time, would occasion its gradual contraction to such an extent as to effect the obliteration of its canal. This statement has been verified by many subsequent experimenters; and it has also been confirmed by the observations of Schwann upon the small arteries of the mesentery of frogs, which he caused to contract slowly by the application of cold water, and then saw dilate again; as much as half an hour being required, however, before they recovered their original size. On the other hand, the application of moderate warmth causes a relaxation of this tonic contraction.—And thus Cold and Heat are two of our most valuable remedial agents, when the Tonicity of the Vascular system is deficient or in excess.

229. We have now to inquire more closely into the influence exerted by the vital and physical properties of the walls of the Arteries, upon the motion of Blood through them. There is no sufficient proof that the vital *Contractility* of these vessels enables them to exert a *propulsive* action in any degree supplementary to that of the Heart; and yet, looking to the general facts already stated, as to the diffusion of the propulsive power through the arterial trunks in many of the lower animals (§ 213), their experimentally-proved reaction upon a distending force (§ 226), and to the circumstance that a kind of rhythmical action has been observed by Wharton Jones in the vessels of the Bat, and by Schiff in those of the ear of the Rabbit, it does not seem by any means improbable that some such power should be preserved, even where there is the greatest concentration of the propulsive force in the muscular walls of the heart. The contractility of the arteries seems to be chiefly exercised, however, in *regulating* the diameter of the tubes in accordance with the quantity of blood to be conducted through them to any part, which will depend upon its peculiar circumstances at the time. Such local changes are continually to be observed in the various phases of normal life as well as in disease; and they will be found to be constantly in harmony with the particular condition of the processes of nutrition, secretion, &c., to which the capillary circulation ministers.

230. The chief purpose served by the *Elasticity* of the Arteries, is one of a purely physical character; its effect being to convert the intermitting impulses which the blood receives from the heart, into a continuous current. The former are very evident in the larger trunks; but they diminish with the subdivision of these, until they entirely disappear in the capillaries, in which the stream is usually equable or nearly so. If

a powerful force-pump were made to inject water, by successive strokes, into a system of tubes with unyielding walls, the flow of fluid at the farther extremities of these tubes would be as much interrupted as its entrance into them. But if an air-vessel (like that of a fire-engine) were placed at their commencement, the flow would be in a great degree equalized; since a part of the force of each stroke would be spent upon the compression of the air included in it; and this force would be restored by the elasticity of the air during the interval, which would propel the stream, until directly renewed by the next impulse. A much closer imitation of the natural apparatus would be afforded by a pipe which had elastic walls of its own; thus if water were forced by a syringe into a long tube of caoutchouc, for example, the stream would be equalized before it had proceeded far. This effect is found to be accomplished, at any point of the Arterial circulation, in a degree proportionate to its distance from the Heart; and in this mode it is, that the intermitting force of the ventricular contraction is almost equably distributed over the whole of the interval between one systole and another, by the contraction of the elastic tubes in the dilatation of which it was at first expended.—Another effect of this elasticity is to distribute the pressure of the blood upon the walls of the arteries, much more equally than would be the case if they formed a system of rigid tubes.

231. The distension of the Arteries that is consequent upon the intermittent injection of blood into their trunks, and the subsequent contraction which results from the elasticity of their walls, give rise to the *pulsation* which is perceptible to the touch in all but the smallest arteries, and which is visible to the eye when they are exposed. This pulsation involves an augmentation of the capacity of that portion of the artery in which it is observed; and it would seem to the touch, as if this were chiefly effected by an increase of *diameter*. It has been experimentally proved, however, that the increased capacity is partly given by the *elongation* of the artery,* which is lifted from its bed at each pulsation, and, when previously straight, becomes curved; the impression made upon the finger by such displacement, not being distinguishable from that which would result from the dilatation of the tube in diameter. A very obvious example of this upheaval is seen in the prominent temporal artery of an old person. The total increase of capacity was estimated by Flourens, from experiments upon the carotid artery, at about 1-23rd part; but it is affirmed by Volkmann† that this must not be considered by any means a constant ratio, since it varies in different arteries, and in the same artery under different circumstances.—The fluctuations of the Pulse in the living body without exposure of the

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* The experiments of Volkmann ("Hämodynamik") have led him to believe, that the transverse dilatation is greater than the longitudinal; but these experiments were made under conditions so different from those of the living artery, that but little weight can, in the Author's opinion, be attached to them. It is to be remembered, however, that every increase in length augments the capacity in only a *simple* ratio; thus a tube of 21 inches in length will only contain *one-twentieth* more than a tube of 20 inches long, of the same diameter. On the other hand, every increase in diameter augments the capacity of the tube in the ratio of the *square* of that increase; thus the capacity of a tube of 21 lines in diameter will be to that of a tube of 20 lines, as 441 : 400, or *one-tenth* more. Consequently, supposing the increase of *capacity* to take place equally in both directions, the increase in longitudinal *dimension* will be far more apparent than the *transverse* enlargement.

† Op. cit., chap. xiv.

Artery can be rendered apparent by the use of an instrument invented by Vierordt, and termed by him the Sphygmograph. It is represented in Fig. 46, and consists of a light lever *a b*, capable of being accurately adjusted by sand or mercury in the cups P P; from the lower surface of the lever a little rod descends, terminating in a button *p*, which is allowed to rest with gentle pressure on the artery R. Its tracings are made by the style *o*, on the revolving drum *s*, and the verticality of the movement is secured by the parallelogram *n n m m*. One of the tracings obtained by this instrument is shown in Fig. 47, in which it will be seen that the upstroke indicating the momentary increase of tension in the vessel consequent upon the systole of the heart, is of equal duration with the downstroke representing the diastole. According to M. Marey, the vis inertia of this instrument is too great, and the periods of systole and diastole are not accurately indicated. To obviate this defect, he has himself constructed an instrument in which the lever is much lighter. Its general arrangement is shown in Fig. 48, where the part B B is applied to the forearm, whilst the pressure on the artery is effected by a very light steel spring, terminating in a small plate of ivory capable of elevation or depression by the screw V. The long arm of the wooden lever L terminates in a fine point touching the plate of smoked glass P, which is made to move gradually forwards by clockwork in the box H. The immediate descent of the lever after its elevation is accomplished by the very delicate spring at R.* The tracings made by this instrument show that under ordinary circumstances the period of ascent or of increase in the tension of the arterial walls is rapid; whilst the period of decrease, during which the elasticity of the larger arteries is acting, is comparatively slow and prolonged. It is perfectly obvious that the fulness of the pulse, or in other words the amplitude of the pulsation, is in inverse ratio to the tension of the walls of the vessel; whilst the hardness of the pulse is

FIG. 46.

The Sphygmograph of Vierordt.

FIG. 47.

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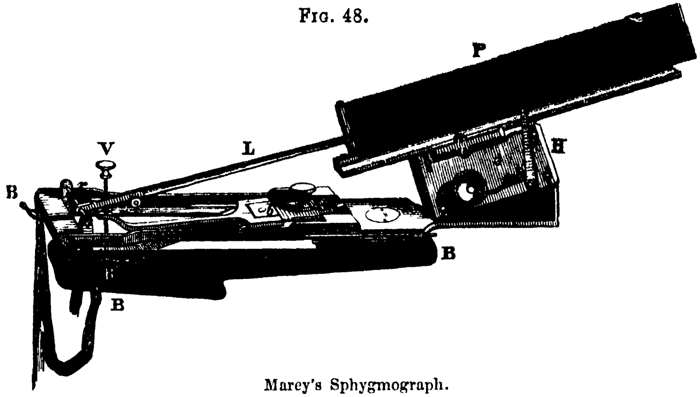
* Mach has recently made an improvement in the construction of the spring and lever. "Sitzungsbericht d. k. Akad. zu Wien," 1863, p. 55.

indicative of arterial tension, and may be produced either by the heart acting with great force and injecting more blood than the arteries can discharge through the capillaries, or by the contraction of the capillaries themselves preventing the escape of the blood from the arteries into the veins. M. Marey has clearly shown how these two conditions of the arterial system may be induced by acting upon the capillaries alone, and either facilitating the passage of the blood through them, or, on the contrary, rendering it more difficult. Thus the tracing obtained by his Sphygmograph, after exposure to a cold bath of one minute's duration, is shown in Fig. 49. It is that of a hard pulse, in which there is considerable tension of the arterial walls; for the contraction of the cutaneous capillaries constitutes an obstacle to the passage of the blood from the arteries. The line of ascension is accordingly sudden and short, the limit of the elasticity of the vessel being soon reached, and the summit of the curve is rounded; whilst the line of descent is protracted and gradual, the resiliency of the vessel being only capable of reacting slowly on the contained blood, and there is no tendency to dichrotism. On the other hand, Fig. 50 shows the effects of a hot-air bath, and presents the characters of a soft full pulse; a pulse of deficient tension, in which the greater boldness of the curves, their sharper summits, and the marked tendency to dichrotism, may particularly be noticed; as well as the

FIG. 48.



Marey's Sphygmograph.

FIG. 49.

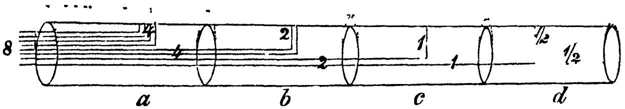
FIG. 50.

increased frequency of the heart's action, corresponding to the diminished exertion which it has to make in propelling the column of blood through the small vessels. A very simple instrument, combining a manometer with a lever and registering apparatus, has been suggested by Naumann;[*] and the following tracing, showing curves analogous to those obtained by M. Marey, was obtained from it in a healthy person. In this the line of ascent appears unbroken, whilst that of descent is interrupted by a slight wave of ascent. The former, representing the duration of the systole, only occupies one-third of the time between two beats; the remaining two-thirds representing the diastole.

Fig. 51.

232. The cause of the interruption in the line of descent, or the dichrotism of the normal pulse, has excited much attention, and several explanations of it have been given. It will be requisite in the first place, however, to consider the nature of the Pulse itself. It was held by Weber, that as with each systole of the Heart the tension of the great vessels near the Heart is increased, the recoil of those vessels propagates a wave of tension through the arteries towards the periphery. The passage of the wave was considered by Weber to be distinct from the propulsion of the fluid; but Volkmann[†] endeavoured to show that they are one and the same. It seemed also to be proved that a certain time was required for the transmission of this pulse-wave from the heart to the periphery of the circulation, since there was a want of synchronism between the ventricular systole and the pulsation of the arteries in various parts of the body, which was indeed measured and stated to be about one-sixth to one-seventh of a second. This theory was invalidated by an observation made by Mr. Colt,[‡] that the pulse was perceptible in every part of the arterial system before the second sound of the Heart; that is, before the closure of the aortic valves; whereas, if the propagation of the wave were due to the recoil of the successive portions of the larger vessels, the second sound of the Heart should constantly precede the pulse, since the first effect of the recoil would be the closure of the aortic valves. Marey has investigated this subject closely, and defines the Pulse to be an effect (perceptible to the touch) of inequality in the tension of the blood contained in an artery. He believes that the contraction of the Heart, which injects a certain quantity of blood into the arteries, is felt instantly throughout the whole arterial system, though it attains its maximum earlier in the vessels near the heart, than in those which are more distant, thus giving rise to an *apparent retardation* of the pulse in the latter. He observes, that if we imagine an artery to be divided into successive

Fig. 52.



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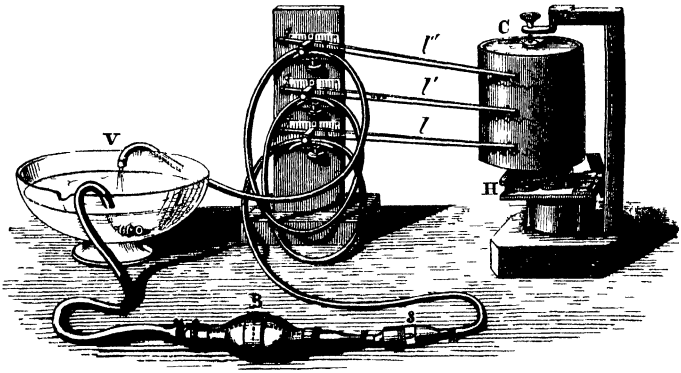
[*] Henle and Meissner's "Zeits. f. Rat. Med.," band xviii p. 194.

[†] Op. cit., chap. x.

[‡] "Med. Gaz.," 1845.

segments *a*, *b*, *c*, *d* (Fig. 52), the portion of blood injected by each cardiac systole enters the first (*a*) with a force which might be represented by 8; here it meets a resistance in the liquid column which already occupies it, and to advance will find in the friction an obstacle amounting, according to the laws of physics, to the square of its velocity; so that the greater the rapidity of the wave, the greater will be its difficulty in advancing; but the walls of the tube are capable of yielding, and they dilate in proportion to the resistance offered. The initial force of the wave is thus decomposed into two parts, one represented by 4, employed in dilating the first segment of the vessel, and the remainder employed in the propulsion of the column of blood into the next segment, when the same decomposition of force is again repeated, and so on, till at the end of a certain length of vessel the direct impulsion will be reduced to an infinitely small quantity. The pressure or tension rapidly attains its maximum in the parts near the impelling organ, because these are exposed to the full force of the impulse; whilst the more distant portions of the vessel attain their maximum of tension more slowly, because the direct impulse is here at first extremely small, and only gradually rises to its full intensity, owing to the gradual restoration by successive acts of recoil of the force which has been spent in dilating the proximal portions of the vessel.*—This explanation of the mode in which the Pulse is produced is fully sustained by the following ingenious experiment devised by M. Marey. A small caoutchouc bag (Fig. 53, B) is filled with valves which permit the contained fluid to move only in the direction of the arrows, and is connected with a long elastic tube forming a rude resemblance to the Heart and Arteries. At three different points of its length the tube is placed under the control of a Sphygmograph, the levers of which, *l* *l′* *l″*, register their movements on the drum C in such a manner that their tracings may be exactly parallel and comparable with one another. Fig. 54 shows such a triple tracing after the india-rubber bag

FIG. 53.



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* For some strictures on this view, see the Memoir of M. Buisson, "Comptes Rendus de la Soc. de Biologie," Sér. iii. t iii, 1862, pt. 1, p. 16.—The value of Marey's Sphygmograph in the diagnosis of aneurism is well shown in the records of some cases in the "Comptes Rendus de la Soc. de Biologie" for 1860.

has been for a few times rhythmically compressed. It is here evident, in the first place, that the commencement of the pulsation, or of the increase of tension in the vascular wall, is the same throughout the whole length of the tube, as shown by the vertical dotted line; though the period at which the maximum or highest point is attained is latest in that portion of the tube (3) most distant from the impelling organ, as is indicated by the direction of the oblique dotted line; and thus it happens that the finger placed upon it, taking cognizance of the maximum alone, would attribute to it a real retardation, whereas in truth there is only an apparent retardation of the impulse propagated through the fluid. Again, it may be noticed that the force of the impulse, or the extent of the vertical movement of the lever, diminishes with increase of distance from the impelling organ, producing the effect which Poisseuille described as "extinction of the wave."

FIG. 54.

233. In now returning to the subject of the dichrotous character of the normal pulse, the three chief theories which have been held regarding it may here be briefly mentioned:—1. That founded on the observations of Volkmann, that when a fluid is driven through an elastic tube by intermitting impulses, two systems of waves arise, one of these being in the fluid, the other in the walls of the vessels, the want of synchronism between which occasions the dichrotous pulse. 2. The view supported by Marey, that the blood injected into the aorta, coursing with rapidity through that vessel, occasions the first pulsation in all the arteries given off from it, but reaching the Iliac region, it meets with a sudden obstacle in the diminished area of the Iliac Arteries as compared with the Aorta, and a rebound occurs which produces an augmentation of the tension in the initial portion of the aorta, and a new pulsation, analogous to the echo of a sound, is conveyed into all the arteries which proceed from this part. This explanation agrees with the observation of Beau, that in the dichrotous pulse the beat is single in the femoral artery, though it may be double in the radial and in all the branches taking origin from the arch of the Aorta.* 3. Lastly, Naumann's explanation, that it results from the impact of the blood against the suddenly closed aortic valves, which, like the sudden stoppage of water flowing through a tap, propagates a jarring impulse through the whole system. According to this view, the dichrotous wave has a central, and not, as Marey supposes, a peripheric origin; and he adduces the fact in accordance with his view, that it uniformly diminishes in intensity, in proportion to the distance from the heart.

234. Since the blood, like other fluids, is almost completely incompressible, all force applied to it becomes perceptible by movement, or if

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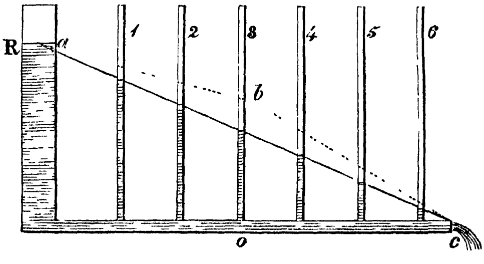
* See Longet's "Physiologie," p. 833.

that be prevented, by lateral pressure exerted against the sides of the vessels. The circumstances that chiefly affect the movement or velocity of the blood, independently of variations in the amount of the propelling force, are those which increase or diminish the friction between it and the vascular walls. Thus it will be retarded by diminution of the diameter of the tubes,* or, as was observed by Hunter, by curves, angles, or divisions in their course,† or by their rigidity,‡ or by increased viscidity in the blood itself; or lastly, by augmentation of its attraction for the tissues, or for the walls of the vessels through which it is coursing. These constitute the obstacles or resistance to the passage of the blood; and with their increase, if the impelling force remain the same, whilst the velocity of its movement is retarded, the amount of lateral pressure exerted is increased. The effects of diminished resistance in diminishing pressure may be understood from a consideration of Fig. 55. For here the height to which the fluid will rise in the small tubes numbered 1—6, is the expression of the pressure of the liquid against the walls of the tube R *o* *c* at different points. If the fluid were stationary, from the closure of the orifice *c*, it would, according to a well-known law, rise to the same height in all; but when a discharge is allowed to take place from *c*, a gradual diminution of pressure, indicated by the diagonal line R *c*, may be observed as the outlet is approached. Now, if the bore

Fig. 55.



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* Thus Poisseuille ("Mem. de l'Acad. des Sciences Sav. Étrang.," t. ix. p. 513 *et seq.*) found that the amount of fluid discharged by small tubes increases, *cæteris paribus*, in proportion to the diameters of these tubes raised to the fourth power; so that a tube of $\frac{1}{100}$th mm. in diameter will discharge 16 times more fluid in a given time, than one of $\frac{1}{200}$th mm. in diameter. The following facts are worthy of recollection in connection with the physics of the circulation:—

The circumference of a cylindrical tube = the radius × 6·28.
The sectional area of ditto = the square of the radius × 3·14.
The amount of discharge from ditto = the sectional area × the velocity of the current.
And lastly, the velocity of the current = the discharge ÷ by the sectional area.

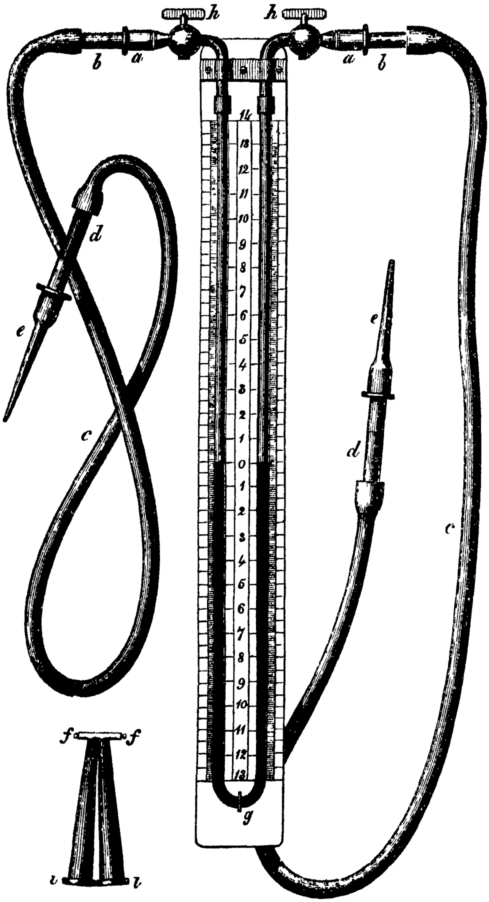
(See Vierordt, "Phys." 1861, p. 88.)

† So Budge ("Physiologie," 1862, p. 309) found that a simple tube (*a*) would deliver more fluid in a given time than a bifid one (*b*), the sectional areas of whose arms were together equal to *a*, and the bifid tube more than a trifid one (*c*) in the proportion of (*a*) 3860 : (*a*) 3400 : (*c*) 3100, the pressure being equal in all three cases.

‡ Thus Marey has shown that whilst elastic and rigid tubes of equal diameters will discharge an equal quantity of fluid as long as the stream is continuous, the moment the stream becomes intermittent an advantage is gained by the elastic tubes, apparently owing to the diminution of friction in the latter, and the conversion of the jetting movement of the fluid into a more continuous, uniform, and steady flow; and herein perhaps we may perceive an explanation of the hypertrophy of the Heart, so frequently observed as a concomitant of a rigid aorta in old age. See "Annal. des Sci. Nat.: Zool.," 1857, t. viii. p. 330; and Marey's "Thèse Inaugurale," 1859.

of the tube be contracted at any part, as from *o* to *c*, an obstacle to the discharge of the fluid will be created, through the increase of friction; the pressure against the walls of the preceding portion of the tube R to *o* will increase, and consequently the line of levels will rise in that part, as indicated by the dotted line R *b c*. If, on the other hand, the outlet be enlarged, the fluid will be discharged more easily, and the line of levels will fall with great rapidity. Upon these principles M. Marey* has constructed an apparatus bearing some resemblance to the different systems of vessels in the body, a constricted portion at *o* representing the Capillaries,† and being preceded by a wider portion for the Arteries, and followed by a still wider one for the Veins. By this instrument it may be shown physically, that the pressure is highest in the Arterial vessels, whilst it rapidly diminishes in the Capillaries, and is lowest in the Veins.‡ These facts, at least as regards the difference in the pressure in the arterial and venous systems, were clearly perceived by Hales, and have been substantiated by Bernard with the differential Manometer, Fig. 56; the two mouthpieces of which, *e e*, being inserted into arteries at the same distance from the Heart, as the two Carotids or the two Crurals, the level of the mercury on the two sides remains equal, indicating equality of

FIG. 56.



Differential Manometer of Bernard.§

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* Brown-Séquard's "Journal de la Physiol.," vol. ii. p. 436.

† The capillaries of the body, though in their aggregate sectional area much larger than the aorta, yet by reason of their smallness, and the consequent great increase of friction against their walls, operate virtually as such a constricted portion.

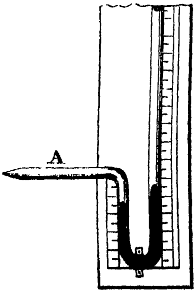
‡ In the living body the pressure rises again in the veins, as their collective calibre is much less than that of the capillaries, though greater than that of the arteries.

§ Bernard, vol. i. p. 205, 1859.

pressure; whilst if one be placed in a more distant artery or into a vein, the mercury constantly rises on that side, thus showing a diminution of pressure or tension. If the contracted or Capillary portion of Marey's apparatus (Fig. 55) be enlarged, the fluid will pass through it with less resistance, and the pressure in the Arterial portion will diminish, and *vice versâ*. This has actually been observed by Bernard in the living subject: for on placing the mouthpieces of his differential manometer into the two facial arteries of a horse, the mercury stood at the same level in each arm of the instrument; but on division of one of the cervical sympathetic nerves, the mercury instantly rose on that side, indicating a diminution in the tension of the vessel. Now it has been ascertained that section of the Sympathetic causes a dilatation of the Capillary vessels, and therefore facilitates the passage of the blood through them; and the counterproof is shown by galvanizing the cut extremity of the Sympathetic, which inducing contraction of the Capillaries, increases the resistance to the passage of the blood from the Arteries, and augments the tension of their walls, as is indicated by the gradual falling of the mercury on the galvanized side, till the pressure there may even exceed that of the healthy one.

235. The absolute pressure of the blood in the living vessels has engaged the attention of many observers. Hales* endeavoured to ascertain it by inserting long pipes into the vessels of living animals, and measuring the height to which the blood rose. In a Mare, when the tube was introduced into the Crural artery, it rose 8 ft. 3 in; in two Horses, 9 ft. 8 in. and 9 ft. 6 in. From parallel experiments upon sheep, oxen, dogs, and other animals, and from the comparison of the calibre of their respective vessels with that of the Human aorta, Hales concluded that the usual force of the heart in Man would sustain a column of blood 7½ feet high, the weight of which would be about 4 lbs. 6 oz. on the square inch. Poisseuille, improving on Hales' method, employed a much more portable instrument in the form of a doubly-bent tube (Fig. 57), containing mercury in the curve, and a solution of carbonate of soda in the mouthpiece, which prevented the formation of clots. A still further improvement was made by Volkmann and Ludwig, by placing Poisseuille's instrument in connection with a revolving drum, on which tracings indicating the fluctuations of the pressure could be taken. The instrument so modified was called the "Kymographion." Poisseuille estimated the pressure in the arteries at 6·3 inches of mercury on the square inch, which he assumed as the standard for all arteries, and for all Mammalia. But the tracings of Ludwig and Volkmann showed that the range of variation was very wide, being in the carotid of the Horse from 6 to 13 inches, and not less in other animals. Bernard has invented a lighter instrument, termed the "Cardiometer," the indications given by which are somewhat higher than those obtained by Poisseuille's apparatus. The following table presents

FIG. 57.



Poisseuille's Hæmadynamometer:—A, mouthpiece.

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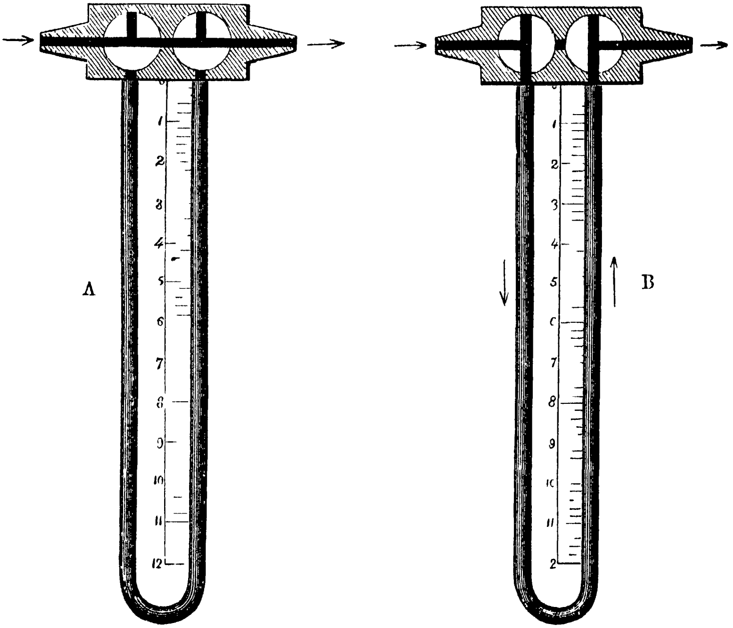
* "Hæmastatics," vol. i. pp. 1–60.

the results of Volkmann's observations* upon the relative lateral pressure at four points of the circulation in different animals; namely (I.) the carotid near its origin, (II.) a peripheral branch of the carotid or some other artery, (III.) a peripheral rootlet of a vein, and (IV.) a jugular vein:—

	I.	II.	III.	IV.
Goat	135	126	41	18
Horse	122	97	44	21·5
Calf	165·5	146	27·5	9

236. The rate of movement of the blood in any artery can only be guessed at as regards the Human subject from the comparative results of experiments upon the lower animals; but several methods have been suggested, by which it may be ascertained in them with some approximation to truth. One of these, employed by Volkmann, and termed by him the Hæmodromometer, is exhibited in Fig. 58, where A shows the instrument as it is inserted between the two cut extremities of an artery or vein. In this position the blood continues to flow in the original direction; but by a simple mechanical arrangement, its course can be suddenly diverted (as in B), through the bent tube filled with water in the direction of the arrows. The rapidity of the current may be readily estimated by timing its course along the scale at the side. A second method is that

Fig. 58.



Volkmann's Hæmodromometer.

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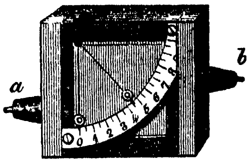
* Op. cit., p. 173.

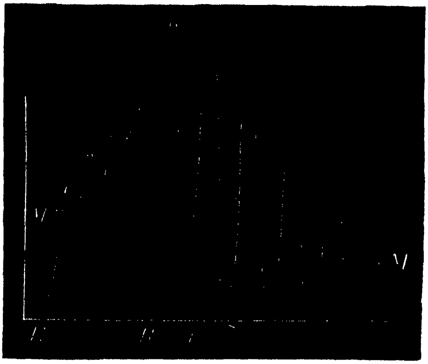
represented in Fig. 59, devised by Vierordt, and termed by him the "Hæmatochometer." This consists of a small glass cell filled with water, with two mouthpieces for insertion into the vessel, and a light vertically-suspended and easily-movable pendulum, placed close to the point of entrance of the current from the upper extremity of the divided artery. The amount of deviation from the perpendicular produced by the instreaming blood on the pendulum, as measured by the scale, indicates the velocity of the current. Volkmann gave the rapidity of the stream in the carotid of the Horse at from 12-17 inches per second, and in the Dog at about 12 inches per second. Vierordt estimated it at 10½ inches per second in the carotid of Man,* and at 2¼ inches per second in the metatarsal artery. Chauveau,† with a similar but somewhat improved instrument, estimated the rapidity of the blood in the carotid of the Horse at 20·28 inches per second during the systole of the heart, falling to 8·78 inches during the diastole.—The influence of expiration and inspiration, and of muscular effort upon the frequency and force of the cardiac pulsations, as indicated by the tracings obtained from a sphygmograph applied to such a vessel as the Radial artery, are of much interest. It can thus be shown that during the act of expiration the frequency of the pulse is considerably augmented (Fig. 60, 1-6); whilst the line of mean pressure (M M) rapidly rises, indicating increased tension in the arterial walls. This is no doubt attributable to the difficulty which the blood in the great veins finds in entering the thorax; for Bernard has shown that any pressure made upon the veins immediately reacts through the capillaries upon the arteries, causing an increase in their tension. During the act of inspiration, on the contrary, the pulsations become slower, the curves much bolder, and the line of mean pressure gradually falls; for then the blood readily enters the thorax, and, as a consequence, the great veins, capillaries, and arterial walls become comparatively flaccid. The influence of muscular exertion, as in a violent effort of expiration with closed glottis, is equally well marked, and may be represented by the same drawing. During the expiratory effort the

FIG. 59.



Hæmatochometer of Vierordt:—*a* and *b*, mouthpieces.

FIG. 60.



Tracing showing effect of Expiration and Inspiration on the Pulse:—1—6, Pulsations during Expiration; from 6 to the end, during Inspiration.

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* "Physiologie," p. 110, 1861.

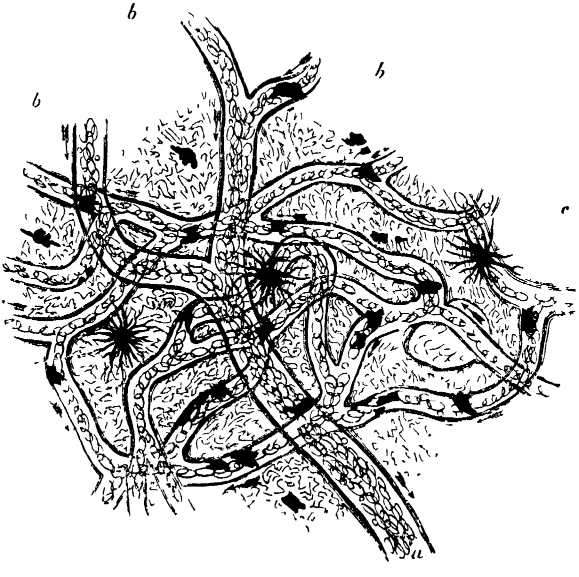
† "Archiv. Gén. de Méd." vol. i. 1861, p. 113, and 'Journal de la Physiol." 1860, p. 695.

number of pulsations augments, and the tracing rises briskly, showing increased tension; and this is occasioned by pressure on the abdominal and thoracic portions of the aorta, which discharge their contents into, and render tense, the peripheral arteries (radial). On the cessation of the effort, the blood flows quickly back from the peripheral arteries into the aorta, which, now uncompressed, possesses less tension than the other arteries, and the line of pressure consequently falls in some instances even below the original level, though the condition of equilibrium is soon restored.*

4. *Movement of the Blood in the Capillaries.*

237. In Man, as in all the higher Animals,—in the adult condition at least,—the Capillary circulation is almost entirely carried-on through tubes having distinct membranous parietes; the only known exception being in the case of the Spleen (§ 130, II.). These tubes commonly form a minutely-anastomosing network (Fig. 61); into which the blood is brought by the ramifications of the arteries on one side, and from which it is returned by the radicles of the veins on the other. The walls of the tubes are composed of a delicate membrane, on the inner surface or in the substance of which numerous nuclei are scattered. These are particularly well seen in the Pia Mater, which consists almost entirely of a congeries of blood-vessels (Fig. 62). The diameter of the Capillaries varies in different animals, in accordance with that of their blood-cor-

FIG. 61.



Capillary plexus in a portion of the web of a *Frog's* foot, magnified 110 diameters:—*a*, trunk of vein; *b, b*, its branches; *c, c*, pigment-cells.

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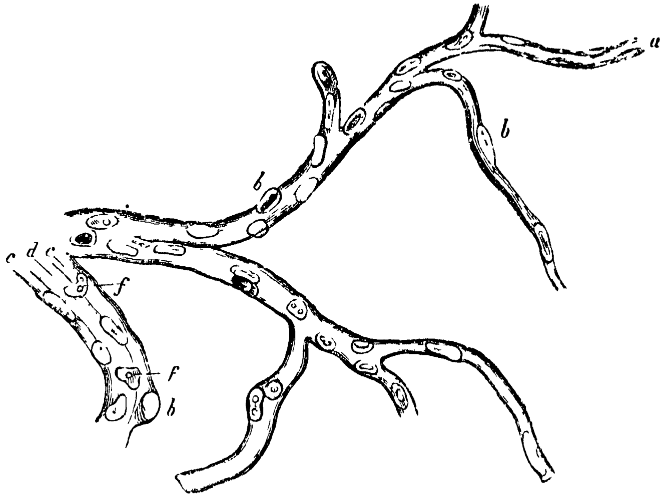
* See M. Buisson in "Comptes Rendus de la Soc. de Biol." Sér. iii. t. iii. pt. i. 1862.

puscles; thus the Capillaries of the Frog are, of course, much larger than those of Man. The ordinary diameter of the latter appears, from

FIG. 62.



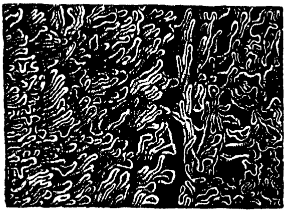
Capillary Blood-vessels from Pia Mater.—*a*, calibre of the tube, partly occupied by oval nuclei, alternately arranged lengthways, and epithelial in their character; *b*, *b*, *b*, nuclei projecting on the exterior of the tube; *c*, *c*, walls, and *d*, calibre, of a large branch; *f*, *f*, oval nuclei, arranged transversely. Magnified 410 diameters.

the measurements of Weber, Muller, and others, to vary from about the 1-3700th to the 1-2500th of an inch; the extremes, however, are stated by Kolliker at as little as 1-5600th and as much as 1-1870th of an inch. As the diameter of the Human capillaries, however, can only be examined after death, it is probable that these statements may not be altogether exact, particularly as tubes of the smallest of the above sizes would not admit ordinary blood-corpuscles. The dimensions of the individual vessels, indeed, are by no means constant; as may be seen by watching the Circulation in any transparent part, for some little time. Putting aside those general changes in diameter which result from circumstances affecting all the capillaries of a part, it may be observed that a single capillary will sometimes enlarge or contract by itself, without any obvious cause. Thus, the stream of blood will sometimes be seen to run into passages which were not before perceived; and it has hence been supposed that they were new excavations, formed by the retreating or removal of the solid tissue through which it passes. But a more attentive examination shows, that such passages are real capillaries, which did not, at the time of the first observation, admit the stream of blood-corpuscles, in consequence of the contraction of their calibre, or of some other local impediment; and that they are brought into view by the simple increase in their diameter. The compression of one of the small arteries will generally occasion an oscillation of the corpuscles of blood in the smallest capillaries, which will be followed by the disappearance of some of them;

but when the obstruction is removed, the blood soon regains its previous velocity and force, and flows into exactly the same passages as before.

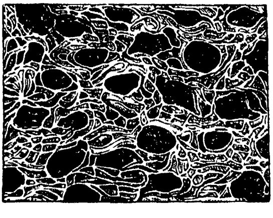
238. The opinion was long entertained, that there are vessels adapted to supply the white or colourless tissues; carrying from the arteries the 'liquor sanguinis,' and leaving the corpuscles behind, through inability to receive them. A considerable development has lately been given to this view by the investigations of Virchow* and others; by whom it has been attempted to be shown that in the various structures included under the term connective tissues, the corpuscles, which are almost constantly found disseminated through them, are to be regarded, like the lacunæ of bone, as centres and storehouses of nutriment, which is again distributed by their caudate prolongations (frequently assuming the form of elastic tissue) to the most distant parts. The idea that Nutrition can *only* be carried-on by means of Capillary vessels, is, however, entirely gratuitous; for there is no essential difference between the nutrition of the non-vascular tissues, and that of the islets in the midst of the network of capillary vessels which traverses the most vascular. In both cases, the nutrient materials conveyed by the blood are absorbed by the cells or other elementary parts of the tissue immediately adjoining the vessels, and are imparted by them to others which are further removed; and the only difference lies in the amount of the portion of tissue which has to be thus traversed, so that we are only required to extend our ideas, from the largest of the islets which we find in the vascular tissues, to the still more isolated structures of which the non-vascular tissues are composed.—The disposition of the Capillaries, both as to the degree of minuteness and the plan of the reticulation which they form, varies so greatly in the different

FIG. 63.



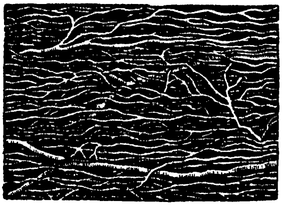
Distribution of *Capillaries* on the surface of the *Skin* of the finger.

FIG. 64.



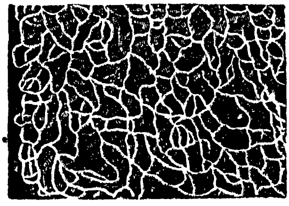
Distribution of *Capillaries* around follicles of *Mucous Membrane.*

FIG. 65.



Distribution of *Capillaries* in *Muscle.*

FIG. 66.



Capillary network around *Fat-cells.*

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* See "Cellular Pathology," *passim.*

vascular tissues, that it is possible to state with tolerable certainty the nature of the part, from which any specimen has been detached,—whether a portion of Skin (Fig. 63), Mucous membrane (Fig. 64), Serous membrane, Muscle (Fig. 65), Nerve, Fat (Fig. 66), Areolar tissue, Gland (Fig. 9), &c. The degree of minuteness is obviously in accordance with the copiousness of the supply of blood which is required for the purposes of its circulation through the part; thus the plexus is closest, where some change is to be effected on the blood itself, as in the absorbent, respiratory, and secreting organs; whilst it is widest in those parts which receive the blood solely for their own nutrition,—the nervous centres and muscles having a more minute reticulation than is seen in the generality of the last-named parts, in virtue of the peculiar activity of the molecular changes which take place in them. But the arrangement of vessels peculiar to each, evidently has reference only to the convenience of the distribution of blood among the elementary parts of the tissue, and varies with their form. It is not possible to imagine that it has any other relation than this to their function; since the function of each separate element of the organ, of which that of the entire organ is the aggregate, is due to its own inherent vital powers,—the supply of blood being only required as furnishing the material on which these are to be exercised.

239. The average *rate of movement* of the blood through the Capillary system, may be determined with tolerable precision by microscopic measurement; and the observations of Hales, Valentin, and Weber concur in representing it to average in the systemic capillaries of the Frog 1·2 inch per minute. In warm-blooded animals, however, the capillary circulation is probably much more rapid than this; the observations of Volkmann upon the mesenteric arteries of the Dog making its rate about 1·8 inch per minute; whilst Ludwig and Vierordt, from observations on the movement of the blood-corpuscles in the retinal capillaries of their own eyes, estimate the rapidity at from one inch in 41 seconds to one inch in 28 seconds. The layer which is in immediate proximity to the wall of the vessels flows from 9 to 17 times more slowly if the movement of the white corpuscles is to be taken as a means of estimating it (Weber). Assuming ·03 inch per second, however, as the rate, and comparing this with the rate of movement of the blood in the larger arteries, which seems on the average to be 11·8 inches per second, it is calculated by Volkmann that the aggregate area of the capillaries (being in an inverse ratio to the rate of the blood's movement through them) must be nearly *four hundred* times that of the arterial trunks which supply them.* Donders, on similar data, estimates it at 500 times greater, and Vierordt at from 800 to 850 times.†

240. That the movement of the Blood through the Capillary system of vessels, is mainly dependent upon the force which it derives from the Heart and from the coats of the Arteries, is a matter altogether beyond dispute. But it is a most important question, not merely in itself, but in its bearing on one of the fundamental questions of Pathology,—the nature of Inflammation,—whether the Capillary circulation is influenced

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* "Hämodynamik," pp. 184, 204.

† "Die Erscheinungen und Gesetze der Stromgeschwindigkeit des Blutes," 1858.

by *any other* agency than the contractile power of the Heart and Arterial system; some Physiologists maintaining that this alone is sufficient to account for all the phenomena of the Capillary circulation; and others asserting that it is necessary to admit some supplementary force, which may be exerted either to assist, retard, or regulate the flow of blood from the Arteries into the Veins. We shall first consider the evidence which may justify an affirmative conclusion as to the existence of such force; and shall then examine into its nature.—No physiological fact seems to the Author to be more clearly proved, than the existence, in the lower classes of Animals, as well as in Plants, of some power independent of a *vis à tergo*, by which the nutritive fluid is caused to move through their vessels.* This power appears to originate in the circulation itself, and to be closely connected with the state of the Nutritive and Secreting processes: since anything which stimulates these to increased energy, accelerates the movement; whilst any check to them occasions a corresponding stagnation. It may be convenient to designate this motor force, by the name of *capillary power;* it being clearly understood, however, that no *mechanical* propulsion is thence implied. On ascending the Animal scale, we find the power which, in the lower organisms, is diffused through the whole system, gradually concentrated in a single part; a new force, that of the Heart, being brought into operation, and the Circulation placed, in a greater or less degree, under its control. Still there is evidence, that the movement of blood through the capillaries is not entirely due to this; since it may continue after the cessation of the Heart's action, may itself cease in particular organs when the Heart is still acting vigorously, and is constantly being affected in amount and rapidity, by causes originating in the part itself, and in no way affecting the Heart.—The chief proofs of these statements will now be adverted-to.

241. When the flow of blood through the Capillaries of a transparent part, such as the web of a Frog's foot, is observed with the Microscope, it appears at first to take place with great evenness and regularity. But on watching the movement for some time, various changes may be observed, which cannot be attributed to the Heart's influence, and which show that a certain regulating or distributive power exists in the walls of the capillaries, or in the tissues which they traverse. Some of these changes, involving variations in the *size* of the capillary tubes, have been already referred-to (§ 237). Others, however, are manifested in great and sudden alterations in the velocity of the current; which cause a marked difference in the rates of the movement of the blood through the several parts of the area under observation. Sometimes this variation extends even to the entire reversal, for a time, of the direction of the movement, in certain of the transverse or communicating branches; the flow always taking place, of course, from the stronger towards the weaker current. Not unfrequently, an entire stagnation of the current in some particular tube precedes this reversal of its direction. Irregularities of this kind, however, are more frequent when the Heart's action is partly interrupted; as it usually is by the pressure to which the tadpole or other animal must be subjected, in order to allow microscopic observations to be made

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* See "Principles of Comparative Physiology," chap. v.

upon its circulation. Under such circumstances, the varieties in the capillary circulation, induced by causes purely local, become very conspicuous; for when the whole current is nearly stagnated, and a fresh impulse from the heart renews it, the movement is not by any means uniform (as it might have been expected to be) through the whole plexus supplied by one arterial trunk, but is much greater in some of the tubes than it is in others; the variation being in no degree connected with their size, and being very different at short intervals.

242. The movement of the blood in the Capillaries of cold-blooded animals, after complete excision of the Heart, has been repeatedly witnessed. In warm-blooded animals, this cannot be satisfactorily established by experiment, since the shock occasioned by so severe an operation much sooner destroys the general vitality of the system; but it may be proved in other ways to take place. After most kinds of natural death, the arterial system is found, subsequently to the lapse of a few hours, almost or completely emptied of blood; this is partly, no doubt, the effect of the tonic contraction of the tubes themselves; but the emptying is commonly more complete than could be thus accounted for, and must therefore be partly due to the continuance of the capillary circulation. It has been observed by Dr. Bennet Dowler,* that in the bodies of individuals who have died from yellow fever, the external veins frequently become so distended with blood *within a few minutes* after the cessation of the heart's action, that, when they are opened, the blood flows in a good stream, being sometimes projected to the distance of a foot or more, especially when pressure is applied above the puncture, as in ordinary blood-letting. It is not conceivable that the slowly-acting tonicity of the arteries should have produced such a result as this; which can scarcely, therefore, be attributed to anything else than the sustenance of the capillary circulation by forces generated within itself. Further, it has been well ascertained that a real process of secretion not unfrequently continues after general or somatic death; urine has been poured-out by the ureters, sweat exuded from the skin, and other peculiar secretions formed by their glands; and these changes could scarcely have taken place, unless the capillary circulation were still continuing. In the early embryonic condition of the highest animals, the movement of blood seems to be unquestionably due to some diffused power, independent of any central impulsion; for it may be seen to commence in the Vascular Area, before it is subjected to the influence of the Heart. The first movement is *towards*, instead of *from*, the centre; and even for some time after the circulation has been fairly established, the walls of the Heart consist merely of cells loosely attached together, and can hardly be supposed to have any great contractile power.

243. The last of these facts may be said not to have any direct bearing on the question, whether the 'capillary power' has any existence in the adult condition; but the phenomena occasionally presented by the fœtus, at a later stage, appear decisive. Cases are of no very unfrequent occurrence, in which the heart is absent during the whole of embryonic life, and yet the greater part of the organs are well developed. In most or all

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* "Researches, Critical and Experimental, on the Capillary Circulation," reprinted from the "New Orleans Medical and Surgical Journal," Jan., 1849.

of these cases, it is true, a perfect twin fœtus exists, of which the placenta is in some degree united with that of the imperfect one; and it has been customary to attribute the circulation in the latter to the influence of the heart of the former, propagated through the placental vessels. This supposition had not been disproved (however improbable it might seem), until a case of this kind occurred, which was submitted to the most careful examination by an accomplished anatomist;* when the decisive result was obtained, that it seemed impossible for the heart of the twin fœtus to have occasioned the movement of blood in the imperfect one, and that some cause present in the latter must have been sufficient for the propulsion of blood through its vessels. It was a very curious anomaly in this case, that the usual functions of the arteries and veins must have been reversed; for the Vena Cava, receiving its blood from the umbilical vein nearly as usual, had no communication with the Arterial system (the Heart being absent), except through the systemic capillaries; to which, therefore, the blood must have next proceeded, returning to the placenta by the umbilical artery. This view of the course of the blood was confirmed by the fact, that the veins were everywhere destitute of valves.—It is evident that a single case of this kind, if unequivocally demonstrated, furnishes all the proof that can be needed, of the existence, even in the highest animals, of a 'capillary power;' which, though usually subordinate to the Heart's action, is sufficiently strong to maintain the circulation by itself, when the power of the central organ is diminished. In this, as in many other cases, we may observe a remarkable capability in the living system, of adapting itself to exigencies. In the acardiac Fœtus, the 'capillary power' supplies the place of the Heart, up to the period of birth; after which, of course, the circulation ceases, for want of due aeration of the blood. It has occasionally been noticed, that a gradual degeneration in the structure of the Heart has taken-place during life, to such an extent that scarcely any muscular tissue could at last be detected in it, but without any such interruption to the circulation as must have been anticipated, if this organ furnishes the sole impelling force.

244. Further, it is a general principle, unquestioned by any Physiologist, and embodied in the ancient aphorism *Ubi stimulus, ibi fluxus*, that, when there is any local excitement to the processes of Nutrition, Secretion, &c., a determination of blood *towards* the part speedily takes place, and the motion of blood *through* it is increased in rapidity; and although it might be urged, that this increased determination may not be the effect, but the cause, of the increased local action, such an opinion could not be sustained without many inconsistencies with positive facts. For it is known that such local determinations may take place, not only as a part of the regular phenomena of growth and development (as in the case of the entire genital system at the time of puberty and of periodical heat, the uterus after conception, and the mammæ after parturition), but also as a consequence of a strictly local cause. Thus, the student is well

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* See Dr. Houston in the "Dublin Medical Journal," 1837.—An attempt was made by Dr. M. Hall ("Edinb. Monthly Journal," 1843) to disprove Dr. Houston's inferences; but a most satisfactory reply was given by Dr. Houston, at the Meeting of the British Association, August, 1843, and published in the "Dublin Journal," Jan., 1844. See also "Edinb. Med. and Surg. Journ.," July, 1844.

aware that, after several hours' close application, there is commonly an increased determination of blood to the brain, causing a sense of oppression, a feeling of heat, and frequently a diminished action in other parts; and, again, when the capillary circulation is being examined under the microscope, it is seen to be quickened by moderate stimuli, and to be equally retarded by depressing agents. All these facts harmonise completely with the phenomena, which are yet more striking in the lower classes of organized beings, and which are evidently in accordance with the same laws.

245. It is equally capable of proof, on the other hand, that an influence generated in the Capillaries may afford a complete check to the circulation in the part; even when the Heart's action is unimpaired, and no mechanical impediment exists to the transmission of blood. Examples of this may be seen in the loss of vitality produced by the prolonged application of cold to a part; also in cases of spontaneous gangrene of the lower extremities, in which the death of the solid tissues is clearly connected with a local decline of the circulation, and in which it has been shown by examination of the limb after its removal, that both the larger tubes and the capillaries were completely pervious; so that the cessation of the flow of blood could not be attributed to any impediment, except that arising from the cessation of some power which exists in the capillaries, and which is necessary for the maintenance of the current through them. The most remarkable evidence on this point, however, is derived from the phenomena of Asphyxia, which will be more fully explained in the succeeding Chapter. At present it may be stated as a fact, which has now been very satisfactorily ascertained, that, if admission of air into the lungs be prevented, the circulation through them will be brought to a stand, as soon as the air which they contain has been to a great degree deprived of its oxygen, or rather has become loaded with carbonic acid; and this stagnation will, of course, be communicated to all the rest of the system. Yet, if it have not continued sufficiently long to cause the loss of vitality in the nervous centres, the movement may be renewed by the admission of air into the lungs. Now although it has been asserted, that the stagnation is due to a mechanical impediment, resulting from the contracted state of the lungs in such cases, this has been clearly proved not to be the fact, by causing animals to breathe a gas destitute of oxygen, so as to produce Asphyxia in a different manner; for the same stagnation results as in the other case.

246. If the phenomena which have been here brought together be considered as establishing the existence, in all classes of beings possessing a circulating apparatus, of a 'Capillary power,' which affords a necessary condition for the movement of the nutritious fluid, through those parts in which it comes into more immediate relation with the solids, the question still remains open, what is the nature of that power?—It is very doubtful whether the Capillaries possess true contractility; for although their diameter is subject to great variation, yet this may be due simply to the elasticity of their walls, which tends to keep them constantly contracted upon the stream of blood that passes through them; and there is no adequate proof that the alterations in their size, which are consequent upon the local application of stimuli, proceed from any other source than the alteration in the quantity of blood delivered to them by the minute

arteries, the very considerable alterations in whose calibre under such influences have been already described (§§ 226, 227). In the experiments of the Profrs. Weber (loc. cit.), the application of the electric stimulus to the capillaries produced no change in their diameter. Even supposing the capillaries, however, to possess such an independent contractility, this could not exert itself in aiding the flow of blood through them, except either by rhythmical alternations of contraction and dilatation, or by some kind of peristaltic movement; and observation completely negatives the idea of the existence of any such movement, since the stream of blood, now rendered continuous by the elasticity of the arteries, passes through the capillaries as through tubes of glass. Hence the notion of any *mechanical* assistance, afforded by the action of the walls of the Capillaries to the movement of blood through them, must be altogether dismissed.

247. There is experimental evidence, however, that the movement of the blood may be affected by any agency which alters the *chemico-vital* relations between the blood and the tissues which it permeates. Thus, when the interrupted electric current was applied to the capillaries by the Profrs. Weber, they noticed that the blood-corpuscles showed a remarkable tendency to adhere to each other and to the walls of the vessels, so as to produce a great amount of friction and a consequent retardation. A very similar set of phenomena has been observed by Mr. Wharton Jones,* as the consequence of the direction of a stream of carbonic acid against the capillary network. And the depression of the vitality of the part, by such injuries as tend to excite Inflammation in it, produces a like stagnation. This effect cannot be attributed to mechanical obstruction in the vessels, for they are usually dilated rather than contracted, when this condition exists; and without any change in the dimensions of a tube, the stream of blood through it may be seen decreasing from extreme velocity to complete stagnation.† That alterations in the chemical state of the blood (involving, of course, important changes in its vital properties) are capable of exercising a most important effect on the Capillary circulation, is shown, not merely by the stagnation of the *pulmonary* Circulation in Asphyxia, but by the curious fact ascertained by Dr. J. Reid,‡ that the blood, when imperfectly arterialised, is retarded in the *systemic* capillaries, causing an increased pressure on the walls of the arteries. He found that, when the ingress of air through the trachea of a Dog was prevented, and the Asphyxia was proceeding to the stage of insensibility,—the attempts at inspiration being few and laboured, and the blood in an exposed artery being quite venous in its character,—the pressure upon the arterial walls, as indicated by the hæmadynamometer applied to the femoral artery, was much greater than usual. Upon applying a similar test to a vein, however, it was found that the pressure was proportionably diminished; whence it became apparent, that there was an unusual obstruction to the passage

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* "Brit. and For. Med. Review," vol. xiv. p. 600.

† See Mr. Paget, Op. cit., p. 311.—The Author had long previously satisfied himself that such was the fact; and is glad to be able to cite the far more extended observations of Mr. Paget on this point, in confirmation of his own.

‡ "Edinb. Med. and Surg. Journ.," April, 1841; and "Anat., Phys., and Pathol. Researches," chap. ii.

of venous blood through the systemic capillaries. After this period, however, the mercury in the hæmadynamometer applied to the artery began to fall steadily, and at last rapidly, in consequence of the diminished force of the heart, and the retardation of the blood in the pulmonic capillaries; but, if atmospheric air was admitted, the mercury rose *instantly*, showing that the renewal of the proper chemical state of the blood restored the condition necessary for its circulation through the capillaries.*

248. It appears from the preceding facts, that the conditions under which the power in question uniformly operates, may be thus simply and definitely expressed: Whilst the injection of blood *into* the Capillary vessels of every part of the system is due to the action of the Heart, its rate of passage *through* those vessels is greatly modified by the degree of activity in the processes, to which it should normally be subservient in them;—the current being rendered more rapid by an increase in their activity, and being stagnated by their depression or total cessation. Or at any rate, to use the more guarded language of Mr. Paget (loc. cit.), we have facts enough to justify the hypothesis, "that there is some mutual relation between the blood and its vessels, or the parts around them, which, being natural, permits the most easy transit of the blood, but, being disturbed, increases the hindrances to its passage."—A physical principle has been put-forth by Prof. Draper,† which seems quite adequate to explain these phenomena. It appears fully capable of proof, that "if two liquids communicate with one another in a capillary tube, or in a porous or parenchymatous structure, and have for that tube or structure different chemical affinities, movement will ensue; that liquid which has the most energetic affinity will move with the greatest velocity, and may even drive the other liquid before it." Now Arterial blood,—containing oxygen with which it is ready to part, and being prepared to receive in exchange the carbonic acid which the tissues set free,—must obviously have a greater affinity for those tissues than Venous blood, in which both these changes have already been effected. Consequently, upon mere physical principles, the arterial blood which enters the Systemic capillaries on one side, must drive before it, and expel on the other side of the network, the blood which has become venous whilst traversing it; but if the blood which enters the capillaries have no such affinity, no such motor power can be developed.—On the other hand, in the Pulmonary capillaries the opposite affinities prevail. The venous blood and the air in the cells of the lungs have a mutual attraction, which is satisfied by the exchange of oxygen and carbonic acid that takes place through the walls of the capillaries; and when the blood has become arterialised, it no longer has any attraction for the air. Upon the very same principle, therefore, the venous blood will drive the arterial before it in the Pulmonary capillaries, whilst respiration is properly going-on: but if the supply of oxygen be interrupted, so that the blood is no longer aerated, no change in the affinities takes place whilst

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* This last fact (as Dr. Reid has remarked) is sufficient to negative the idea of Mr. Erichsen, that the obstruction is caused by the *contraction of the capillaries* under the stimulus of venous blood ("Edinb. Med. and Surg. Journ.," Jan., 1845); for all experiments agree in showing, that such contraction can only be excited by the application of a stimulus for some minutes, and that relaxation takes place still more slowly. (§ 226).

† "Treatise on the Forces which produce the Organization of Plants," pp. 22-41.

it traverses the capillary network; the blood continuing venous, still retains both its need of a change, and its attraction for the walls of the capillaries; and its egress into the pulmonary veins is thus resisted, rather than aided, by the force generated in the lungs.—The change in the condition of the blood, in regard to the relative proportions of its oxygen and carbonic acid, is the only one to which the Pulmonary circulation is subservient; but in the Systemic circulation, the changes are of a much more complex nature, every distinct organ attracting to itself the peculiar substances which it requires as the materials of its own nutrition, and the nature of the affinities thus generated being consequently different in each case. But the same law may be considered to hold good in all instances. Thus the blood conveyed to the Liver by the portal vein, contains the materials at the expense of which the bile-secreting cells are developed; consequently the tissue of the Liver, which is principally made-up of these cells, possesses a certain degree of affinity or attraction for blood containing these materials; and this is diminished, so soon as they have been drawn from it into the cells around. Consequently the blood of the portal vein will drive before it, into the hepatic vein, the blood which has traversed the capillaries of the portal system, and which, in doing so, has given-up the elements of bile to the solid tissues of the liver.*

249. The influence which the Nervous System is known to exert upon the functions of Nutrition and Secretion, which are very intimately related to the movement of the blood in the Capillaries, would lead us to expect that it should exercise some like influence over that movement itself. And two distinct channels for such an influence may be assigned with much probability; first, the control exercised by the Sympathetic system over the diameter of the smaller arteries, which will thus regulate the rate at which the blood is supplied to the capillary plexus; and second, the direct agency of Nerve-force in stimulating, retarding, or modifying those molecular changes, in which the Nutritive and Secretory operations consist. (See PRIN. OF GEN. PHYS.).—That the ordinary action of this force is not required to sustain the Capillary circulation, is clearly proved by the continuance of the flow without any apparent alteration, after section of the nerves of the part, as has been observed by Müller, Wharton Jones, and others; and this corresponds with the well-known fact, that the Nutritive and Secretory processes may take place after Nervous agency has been thus suspended. But it seems indubitable that a sudden and violent 'shock' to the nervous centres may exert the same antagonistic influence on the movement of blood in the Capillaries, as we have seen it to do on the Heart's action (§ 216): for this appears alike from the immediate and total annihilation of all vital activity which is consequent upon such an injury, and from direct observation in such an experiment as the following, made by Dr. Wilson Philip. "The web of one of the hind legs of a frog was brought before the microscope; and while Dr. Hastings observed the circulation, which was vigorous, the brain was crushed by the blow of a hammer. The vessels of the web *instantly* lost their power, the circulation ceasing; an effect which cannot arise, as we have seen, from the ceasing of the action of the heart. [Dr.

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* For further information, the reader is referred to Mr. Savory's excellent Review of the whole of this subject, with original experiments, in the "Brit. & For. Med.-Chir. Review," vol. xv. p. 372, and vol. xvi. p. 12.

Philip here refers to experiments, by which it was ascertained that the circulation in the capillary vessels of the frog will continue for several minutes after interruption of the heart's action.] In a short time the blood again began to move, but with less force. This experiment was repeated, with the same result. If the brain is not completely crushed, although the animal is killed, the blow, instead of destroying the circulation, increases its rapidity."*

5. *Movement of the Blood in the Veins.*

250. The Venous system takes its origin in the small trunks that are formed by the re-union of the Capillaries; and it returns the blood from these to the Heart. The structure of the Veins is essentially the same with that of the Arteries; but the fibrous tissue of which their middle coat is made-up, bears more resemblance to the areolar tissue of the skin, than it does to the true elastic tissue, and presents the distinguishing feature of Laminæ running longitudinally as well as transversely; and the muscular fibre-cells are usually much fewer in number, and are sometimes wanting altogether.† The *elasticity* of the Veins is shown by the jet of blood which at first spouts-out in ordinary venesection, when, by means of the ligature, a distension has been occasioned in the tubes below it. Though the walls of the Veins are thinner, they yet resist pressure better than the Arteries. In an experiment of Wintringham‡ the Aorta burst when the pressure rose to 158 lbs., whilst the Vena Cava only gave way when it reached 176 lbs. A slight *contractility* on the application of stimuli, and on irritation of the Sympathetic nervous fibres, has been observed; but this is not so decided as in the arteries. The whole capacity of the Venous system is considerably greater than that of the arterial; the former is usually estimated to contain from 2 to 3 times as much blood as the latter, in the ordinary condition of the circulation; and when we consider the great proportion which the Veins in almost every part of the body bear to the arteries, we shall scarcely regard even the larger of these ratios as exaggerated. Of course the rapidity of the movement of the blood in the two systems will bear an inverse ratio to their respective capacities; thus if, in a given length, the veins contain three times as much blood as the arteries, the fluid will move with only one-third of the velocity. Even at their origins in the capillary plexus, the veins are larger than the arteries which terminate in the same plexus; so that wherever the arterial and venous networks form distinct strata, they are readily distinguished from each other. The Veins are remarkable for the number of *valves* which they contain, formed of duplicatures or loose folds of the internal tunic, between the component laminæ of which, contractile fibres are interposed; and also for the dilatations behind these, which, when distended, give them a varicose appearance. The valves are single in the small veins, the free edge of the flap closing against the opposite wall of the vein; in the larger trunks they are double; and in

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[*] "Experimental Inquiry into the Laws of the Vital Functions," 4th edition, p. 52.

[†] The following, according to Prof. Kölliker ("Manual of Human Histology," Syd. Soc., vol. ii. p. 307), are Veins which are unprovided with muscular structure:—The veins of the uterine portion of the placenta; the veins of the cerebral substance and pia mater; the sinuses of the dura mater; Breschet's veins of the bones; the venous cells of the corpora cavernosa in the male and female; and probably the venous cells of the spleen.

[‡] "Experimental Inquiry," &c., 1740.

a few instances they are composed of three flaps. The object of these valves is evidently to prevent the reflux of blood; and we shall presently see, that they are of important use in assisting in the maintenance of the venous circulation. They are most numerous in those veins which run among parts affected by muscular movement; and they are not found in the veins of the lungs, of the abdominal viscera, or of the brain.

251. The movement of the blood through the Veins is, without doubt, chiefly effected by the *vis à tergo* or propulsive force, which results from the action of the heart and arteries; this, as already shown (§ 235), is very greatly diminished by the time that it acts on the blood in the veins; but the resistance to the onward movement of the blood is now so slight, that a very feeble power is adequate to overcome it. There are some concurrent causes, however, which are supposed by some to have much influence upon it, and of which the consideration must not be neglected.—One of these has been found by some Physiologists, in the *inspiratory movement;* this is supposed to draw the blood of the Veins into the chest, in order to supply the vacuum which is created there at the moment of the descent of the diaphragm. That the movement in question has *some* influence on the flow of venous blood into the chest, is evident from the occurrence of the *respiratory pulse*, long ago described by Haller; which may be seen in the veins of the neck and shoulder in thin persons, and in those especially who are suffering from pulmonary diseases. During Inspiration, the veins are seen to be partially emptied: whilst during Expiration they become turgid, partly in consequence of the accumulation from behind, and of the check in front; and partly (it may be) in some cases, through an absolute reflux from the veins within the chest (§ 219). The fact that in the immediate neighbourhood of the chest, the flow of blood towards the heart is aided by inspiration and impeded by expiration, is further proved by Sir D. Barry's experiment, which consisted in introducing one extremity of a tube into the jugular vein of a Horse, and the other into water, which exhibited an alternate elevation and depression with inspiration and expiration; this has been repeated and confirmed by several Physiologists. On the other hand, the *expiratory* movement, while it directly causes accumulation in the veins, will assist the heart in propelling the blood into the arteries; and by the combined action of these two causes is produced among other effects, the rising and sinking of the Brain, synchronously with expiration and inspiration, which are observed when a portion of the cranium is removed. Several considerations, however, agree in pointing to the conclusion, that no great efficacy can be rightly attributed to the Respiratory movements, as exerting any *general* influence over the Venous circulation. The Pulmonary circulation being entirely within the chest, cannot be affected by variations in atmospheric pressure; the entire venous circulation of the fœtus, also, is independent of any such agency. Again, it has been shown experimentally by Dr. Arnott and others, that no suction-power exerted at the farther end of a long tube, whose walls are so deficient in firmness as are those of the Veins, can occasion any acceleration in a current of fluid transmitted through it; for the effect of the suction is destroyed, at no great distance from the point at which it is applied, by the flapping-together of the sides of the vessels. This tendency may be counteracted, however, as Bérard

maintains,* by firm adhesions of the external surface of the Veins to the adjoining parts: such adhesions undoubtedly take place in many parts, as for instance in the Hepatic and Innominate Veins, and in the lower part of the Jugular Vein; and therefore, to that extent at least, the venous circulation must be influenced by the respiratory movements.—Another agency which certainly assists the venous circulation in some animals, is the rhythmical contraction of the walls of the veins, which has been observed to occur 8 to 10 times per minute in the transparent membrane of the wing of the Bat, the amount of contraction being about one-fourth of the diameter of the vessel (Wharton Jones).

252. One of the most powerful of the general causes which influence the Venous circulation, is doubtless the frequently-recurring *pressure of the muscles* upon their trunks. In every instance that Muscular movement takes place, a portion of the Veins of the part will undergo compression; and as the blood is prevented, by the valves in the veins, from being driven-back into the small vessels, it is necessarily forced on towards the heart. As each set of muscles is relaxed, the veins compressed by it fill-out again, to be again compressed by the renewal of the force. That the general Muscular movement is an important agent in maintaining the circulation, at a point above that at which it would be kept by the action of the heart and arterial system alone, appears from several considerations. The pulsations are diminished in frequency by rest, accelerated by exertion, and very much quickened by violent effort (§ 224 *d*). In all kinds of exercise, and in almost every sort of effort, there is that alternate contraction and relaxation of particular groups of Muscles, which has been just mentioned as affecting the flow of blood through the veins; and there can be little doubt that the increased rapidity of the return of blood through them, is of itself sufficient cause for the accelerated movements of the heart. When a large number of muscles are put in action after repose, as is the case when we rise-up from a recumbent or a sitting posture, the blood is driven to the heart with a very strong impetus; and if that organ should be diseased, it may arrive there in a quantity larger than can be disposed-of; so that sudden death may be the result. Hence the necessity for the avoidance of all sudden and violent movements, on the part of those who labour under either functional disorder or structural disease of the centre of the circulation.

253. The Venous circulation is much more liable than the Arterial, to be influenced by the force of Gravity; and this influence is particularly noticeable, when the tonicity of the vessels is deficient.—The following experiments performed by Dr. C. J. B. Williams,† to elucidate the influence of deficient firmness in the walls of the vessels, and of gravitation, over the movement of fluids through tubes, throw great light on the causes of *venous congestion.* A tube with two equal arms having been fitted to a syringe, a brass tube two feet long, having several right angles in its course, was adapted to one of them, whilst to the other was tied a portion of a rabbit's intestine four feet long, and of calibre double that of the brass tube, this being arranged in curves and coils, but without angles or crossings. When the two tubes were raised to the same

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* "Cours de Physiologie," t. iv. p. 62.

† "Principles of Medicine," 2nd edit., p. 188.

height, the small metal tube discharged from two to five times the quantity of water discharged in a given time by the larger but membranous tube; the difference being greatest when the strokes of the piston were most forcible and sudden, by which the intestine was much dilated at its syringe-end, but conveyed very little more water. When the discharging ends were raised a few inches higher, the difference increased considerably. the amount of fluid discharged by the gut being much diminished; and when the ends were raised to the height of eight or ten inches, the gut ceased to discharge, each stroke only moving the column of water in it, and this subsiding again, without rising high enough to overflow. When the force of the stroke increased, the part of the intestine nearest the syringe burst.—From these experiments it is easy to understand, how any deficiency of 'tone' in the Venous system will tend to prevent the ascent of the blood from the depending parts of the body, and will consequently occasion an increased pressure on the walls of the vessels, and an augmentation in the quantity of blood they contain. All these conditions are peculiarly favourable to the escape of the watery part of the blood from the small vessels; and this may either infiltrate into the areolar tissue, or it may be poured into some neighbouring serous cavity, producing dropsy. Thus it happens that such effusions may often be traced to that state of deficient vigour of the system, which peculiarly manifests itself in want of tone of the blood-vessels; and that it is relieved by remedies which restore this. In many young females of leucophlegmatic temperament, for example, there is a tendency to swelling of the feet, by œdematous effusion into the areolar tissue. in consequence of the depending position of the limbs; the œdema disappears during the night, but returns during the day, and is at its maximum in the evening. And the congestion which frequently manifests itself in the posterior parts of the body, towards the close of exhausting diseases in which the patient has lain much upon his back, is attributable to a similar cause; of such congestion, effusions into the various serous cavities are frequent results; and such effusions, taking place during the last hours of life, are often erroneously regarded as the source of death. To the same cause we are to attribute the varicose state of the veins of the leg, which is so common amongst persons of relaxed fibre, and especially in those whose habits require them to be much in the erect posture; and this distension occasionally proceeds to complete rupture, the causes of which are fully elucidated by the experiments just cited.

6. *Peculiarities of the Circulation in different Parts.*

254. In several portions of the Human body, there are certain varieties in the distribution and in the functional actions of the blood-vessels, which should not be omitted in a general account of the Circulation.—Of these, we have in the first place to notice the apparatus for the *Pulmonary* circulation; the chief peculiarity of which is, that *venous* blood is sent *from* the heart, through a tube which is arterial in its structure, whilst *arterial* blood is returned *to* the heart, through a vessel whose entire character is that of a vein. The movement of the blood through these is considerably affected by the physical state of the lungs themselves; being retarded by any causes which can occasion pressure on the vessels (such

as over-distension of the cells with air, obstruction of their cavity by solid or fluid depositions, or by foreign substances injected into them, &c.); and proceeding with the greatest energy and regularity when the respiratory movements are freely performed.—The *Portal* circulation, again, is peculiar, in being a kind of offset from the general or systemic circulation, and also in being destitute of valves; and it may be surmised with much probability, that the purpose of their absence is, to allow of an unusually free passage of blood from one part of that system to another, during the very varying conditions to which it is subjected.—Another very important modification of the Circulating system, is that which presents itself within the *Cranium*. From the circumstance of the cranium being a closed cavity, which must be always filled with the same total amount of contents, the flow of blood through its vessels is attended with some peculiarities. The pressure of the atmosphere is here exerted, rather to keep the blood in the head, than to force it out; and it might accordingly be inferred, that, whilst the quantity of cerebral matter remains the same, the amount of blood in the cranial vessels must also be invariable. This inference appeared to derive support from the experiments of Dr. Kellie.* On bleeding animals to death, he found that, whilst the remainder of the body was completely exsanguine, the usual quantity of blood remained in the arteries and veins of the cranium; but that if an opening was made in the skull, these vessels were then as completely emptied as the rest. In the experiments performed by Kussmaul and Tenner,† it was found on trephining the skull and compressing the carotids, that the brain, especially after removal of the dura mater, became very pale, and retreated from the opening to so great an extent as to form a cup 2½ mm. in depth; whilst on releasing the pressure, it assumed a deep rose colour and became convex. When, however, they luted a piece of glass air-tight into the hole made by the trephine, as suggested by Donders, the phenomena were no longer the same, for no movement of any kind could then be perceived in the brain, which remained in all cases immovably in contact with the glass plate; but the same changes in the tint of the cerebral substance, on checking and again restoring the current in the arteries, were observed. These experiments, therefore, appear to furnish indisputable evidence that the circulation of blood through the Brain varies with the general conditions of the vascular system, and is not, as Dr. Kellie's experiments appeared to show, independent of them. Moreover, in disordered states of the circulation, the quantity of blood in the vessels of the cranium may be for a time diminished by a sudden extravasation, either of blood or serum, into the cerebral substance; and the amount of interior *pressure* upon the walls of the vessels may also be considerably altered, even when there is no difference in the *quantity* of fluid contained in them.‡ It seems highly probable that in the delicate and extensive system of capillaries found in the pia mater and choroid plexus, a provision is made by which a large quantity of cerebro-spinal fluid can be effused or absorbed in a short space of time, to compensate for sudden changes in the balance of the circulation.

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* "Edinburgh Medico-Chirurgical Transactions," vol. i.

† See their Essay (Syd. Soc. Translation, p. 39 *et seq.*, 1859).

‡ The results of the experiments of Dr G. Burrows ("Medical Gazette," April and May, 1843) fully confirm the views stated above.

255. The *Erectile Tissues* present another curious modification of the ordinary vascular apparatus. The chief of these are the corpora cavernosa in the penis of the male, and in the clitoris of the female; the collection of similar tissues round the vagina and in the nymphæ of the female; and the nipple in both sexes. In all these situations, erection may be produced, and in the case of the penis, *emissio seminis* may be effected, by local irritation. The nerves implicated in producing erection in the Dog were found by Eckhard* to be, first, the *Nn. pudend. communes* proceeding from the sciatic plexus, and supplying the musculi ischio-cavernosi, the corpora cavernosa of the penis, and membranous portion of the urethra; and second, the *Nervi erigentes* proceeding from the sacral nerves and entering the hypogastric plexus. This plexus contains minute ganglia, communicates with the posterior mesenteric plexus, and furnishes branches to the bladder, prostate gland, rectum, and membranous portions of the urethra. After division of the former, or common pudendal nerves in the Dog, Eckhard found it impossible to produce erection of the penis or emission of semen by direct irritation of the penis. The Nervi erigentes are, however, the chief excitors to erection, for on exposing and irritating them, swelling of the penis, gradually proceeding forwards to the glans, immediately commenced. Erection may also occur as a result of certain emotional conditions of the mind, the influence of which is probably transmitted through the Sympathetic nerve, as it may be experienced even in cases of paraplegia. The erectile tissue appears essentially to consist of a plexus of veins with varicose enlargements, inclosed in a fibro-muscular envelope with trabecular partitions; the contraction of which is doubtless in some way concerned in the result. In the penis, as first pointed-out by Prof. Muller,† there are two sets of arteries; those of one set, destined for the nutrition of the tissues, communicating with the veins in the usual way, through a capillary network; whilst the others, termed by him the 'helicine arteries,' are short tendril-like branches, which project into the veins (covered, however, by their lining membrane), sometimes singly, and sometimes in tufts, ending abruptly by dilated extremities. It was maintained by Muller, that the dilated ends of these helicine arteries communicate directly with the venous cavities, since injection thrown into the former always fills the latter, although no distinct apertures have been seen in them; and Kolliker states that he has frequently found them giving-off delicate, almost capillary vessels, which discharge themselves into the venous spaces.‡—The proximate cause of the erection of the penis, has been stated by some to be the action of the ischio-cavernosi and the bulbo-cavernosus muscles, in compressing the veins which return the blood from the penis; but although these muscles probably afford assistance in completing and strengthening the erection, they are unable to effect it by their own act; and it is obvious that no analogous power can be exerted in other erectile organs, the nipple for example.—It is maintained by Prof. Kolliker, that the office of

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* "Beitrage zur Anat. und Phys.," Giessen, 1863.

† 'Entdeckung der bei der Erection wirksamen Arterien,' in "Muller's Archiv," 1835, p. 202.

‡ For excellent accounts of the minute anatomy of the Penis, see Langer, "Sitzungsbericht d. Akad. zu Wien." xlvi., 1863, p. 120; Henle, "Nachr. v. d. Univ. v. k. Gesell. d. Wiss. zu Gotting.," 1863; and Henle and Pfeuf., "Zeits." xviii. pt. i. 1863.

the muscular fibres which pass in every direction amongst the dilated veins, is to keep them compressed in the intervals of erection, so as to prevent them from being distended by the *vis a tergo* of the blood, and that the stimulus to erection, which is usually conveyed through the nervous system, so operates upon these fibres as to occasion their *relaxation*, whereby the free distension of the cavernous veins and of the arterial diverticula is permitted He refers, moreover, to the excessive contraction of erectile organs which is induced by cold,* and to the effect of warmth in favouring their enlargement, as confirmatory of this view; and considers that no other agency is required Now although we are so accustomed to consider the stimulus of innervation as exerted in producing muscular *contraction*, yet since, in the act of Blushing, there is undoubtedly a *relaxation* of the muscular walls of the blood-vessels under the influence of emotional excitement, there seems a strong analogical probability (at any rate, no *a priori* improbability) that the same may be the case with the act of Erection At the same time it must be understood that the act of erection does not consist of mere passive venous congestion, but that the circulation in the whole organ is greatly increased, Eckhard stating that in the Dog he obtained eight times more blood from the veins of the penis at the period of erection than during the intervals

CHAPTER VII

OF RESPIRATION

1 *Nature of the Function and Provisions for its Performance*

256 THE Nutritive fluid, in its circulation through the capillaries of the system, undergoes great alterations, both in its physical constitution and in its vital properties It gives-up to the tissues with which it is brought into contact, some of its most important elements, and, at the same time, it is made the vehicle of the removal, from these tissues, of ingredients which are no longer in the state of combination that fits them for their offices in the Animal Economy To separate these ingredients from the general current of the circulation, and to carry them out of the system, is the great object of the Excretory organs, the importance of whose respective functions will vary, it is very evident, with the amount of the ingredient which they have to separate, and with the deleterious influence which its retention would exert on the welfare of the system at large Of all these injurious ingredients, Carbonic Acid is without doubt the one most abundantly introduced into the nutritive fluid, and it is also most deleterious in its effects on the system, if allowed to accumulate. —We find, accordingly, that the provision for the removal of this substance from the blood is one of peculiar extent and importance, especially in the higher forms of animals, and further, that instead of being effected

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* The application of *moderate* cold, however, (as in putting on a clean shirt) frequently occasions erection of the male nipple.

by an operation peculiarly *vital* (like other acts of Excretion), its performance is secured by being made to depend upon simple *physical* conditions, and is thus comparatively little susceptible of derangement from disorder of other processes. All that is requisite for it, is the exposure of the Blood to the influence of the Atmospheric air (or, in aquatic animals, of air dissolved in water), through the medium of a membrane that shall permit the 'diffusion of gases;' an interchange then taking place between the gaseous matters on the two sides,—Carbonic acid being exhaled from the Blood, and being replaced by Oxygen from the air. Thus the extrication of Carbonic acid is effected in a manner that renders it subservient to the introduction of that element which is required for all the most active manifestations of vital power; and it is in these two processes conjointly, not in either alone, that the function of Respiration essentially consists.—We shall now inquire into the sources from which Carbonic acid is produced in the living body, and the causes of the demand for Oxygen.

257. The vital activity of the organism at large involves a continual change in its constituent parts; and those which (so to speak) live the fastest, usually die the soonest, and pass most readily into decay (CHAP. VIII., Sect. 1). Hence in the very performance of the Organic functions which concur to effect the Nutrition of the body, there is a constant source of disintegration; and one of the chief products of the decay of the tissues, which is consequent upon their loss of vitality, is Carbonic acid.—Thus the *most general* object of the Respiratory process, which is common to all forms of organized being, is the extrication of this product from the system; and the demand for aeration hence arising, will vary with the activity of the nutritive operations. Now the rate of life, and consequently the amount of disintegration, in any organized structure, depend in great measure upon the temperature at which it is maintained; and thus it happens that the production of Carbonic acid from this source, at the ordinary rate of vital activity, is much more rapid in 'warm-blooded' than in 'cold-blooded' animals, and that the former suffer far more speedily than the latter from the privation of air. But when the temperature of the Reptile is raised by external heat to the level of that of the Mammal, its need for respiration increases, owing to the augmented waste of its tissues. When, on the other hand, the warm-blooded Mammal is reduced, in the state of hybernation, to the level of the cold-blooded Reptile, the waste of its tissues diminishes to such an extent, as to require but a very small exertion of the respiratory process to get-rid of the carbonic acid, which is one of its chief products. And in those animals which are capable of retaining their vitality when they are frozen, or when their tissues are completely dried-up, vital activity and disintegration are alike entirely suspended, and consequently there is no carbonic acid to be set-free.

258. But another source of Carbonic acid to be set-free by the Respiratory process, and one which is peculiar to animals, consists in the rapid changes which take place in the Muscular and Nervous tissues, in the very act of performing their peculiar functions; the development of the Muscular and of the Nervous forces involving, as the very condition of their production, a change in the substance of these tissues respectively; in which change a large quantity of Oxygen is consumed, and a large amount of Carbonic acid is generated. Hence in Man, as in all Animals

in which the Nervo-Muscular apparatus constitutes the essential part of the organism, a powerful demand for Respiration is created by its activity; the amount of oxygen taken-in, and of carbonic acid exhaled, being determined, *cœteris paribus*, by the degree in which this apparatus is exercised.—That Carbonic acid is set-free ready-formed by the muscles, and is not exclusively generated by the oxidation of the products of their disintegration after the reception of these into the blood-current, has been shown by the experiments of Dr. G. Liebig;* who found that carefully-prepared frogs' muscles absorb oxygen and exhale carbonic acid so long as their contractility lasts, even when they have been completely deprived of blood. So that, in this instance, as probably in all others of its kind, the first interchange of gases takes place in the parenchyma of the organs themselves,—oxygen being drawn by them from the blood, and carbonic acid being imparted to it; and the converse change must be as constantly effected in the lungs, in order that the circulating medium may be maintained in the requisite state of purity.

259. Besides these sources of Carbonic acid which are common to all Animals, there is another which is restricted (or nearly so) to the two highest classes, Birds and Mammals; these being distinguished by their power of maintaining a constantly-elevated temperature. A part of this Heat is generated by the oxygenation of the components of their disintegrating tissues, and of their blood, the metamorphosis of which takes place at a very rapid rate; but where this is not sufficient, their power of maintaining their temperature depends upon the *direct* combination of certain elements of the food with the oxygen of the air, by the combustive process.—The quantity of carbonic acid that is generated directly from the elements of the food, seems to vary considerably in different animals, and in different states of the same individual. In the Carnivorous tribes, which spend the greater part of their time in a state of activity, it is probable that the quantity which is generated by the waste or metamorphosis of the tissues is sufficient for the maintenance of the required temperature; and that little or none of the carbonic acid set-free in respiration, is derived from the direct combustion of the materials of the food. But in Herbivorous animals of comparatively inert habits, the amount of metamorphosis of the tissues is far from being sufficient; and a large part of the food, consisting as it does of substances that cannot be applied to the nutrition of the tissues, is made to enter into direct combination with the oxygen of the air, and thus to compensate for the deficiency. In Man and other animals, which can sustain considerable variations of climate, and can adapt themselves to a great diversity of habits, the quantity of carbonic acid formed by the direct combination of the elements of the food with the oxygen of the air, will differ extremely under different circumstances. It will serve as the *complement* of that which is formed in other ways; so that it will diminish with the increase, and will increase with the diminution, of muscular activity. It will also vary in an inverse ratio to the external temperature, increasing with its diminution (as more heat must then be generated), and diminishing with its increase; the effect of external heat being thus precisely opposite, in the warm-blooded animal, to that which it exerts on the

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* "Bericht d. Akad. d. Wissensch. zu Berlin," 1850, §§ 339-347.

cold-blooded (§ 257).—In all cases, if a sufficient supply of food be not furnished, the store of fat is drawn upon; and if this be exhausted, the animal dies of cold.

260. To recapitulate, then, the sources of Carbonic Acid in the animal body are threefold.—I. The continual decay of the tissues common to all organized bodies, which is favoured by whatever promotes their vital activity, and is retarded by every influence that depresses it.—II. The metamorphosis peculiar to the Nervous and Muscular tissues, which is the very condition of the production of their power, and which therefore bears a direct relation to the degree in which they are exerted.—III. The direct conversion of the carbon and hydrogen of the food into carbonic acid and water, which is peculiar to warm-blooded animals; and which varies in quantity, in accordance with the amount of heat to be generated.

261. The activity of the process of Respiration in any Animal, is, as a general rule, in direct proportion to the smallness of the Corpuscles of its Blood; for these, as has already been shown (§ 168), are the carriers of oxygen; and it is evident that a given weight of smaller globules will offer a larger surface for the absorption of oxygen, than an equal weight of larger corpuscles. Hence in Fishes and Reptiles, which possess large corpuscles, the provision for the aeration of the blood is much less perfect, and the amount of oxygen absorbed, and of carbonic acid eliminated is considerably smaller, than in the case of Mammals and Birds, the corpuscles of whose blood are remarkably minute. At the same time the size of the lungs in the latter classes is far less in proportion to their bulk than in most Reptiles; but this diminution is more than compensated by the minute subdivision of their cavities, by the peculiarity of the distribution of their blood-vessels, and by the arrangements whereby a continual and rapid interchange, both of the blood and of the air, is provided-for.—The following are the points of most importance in the structure of the Human Lung.* The walls of the bronchial tubes contain distinct longitudinal and circular layers of fibrous structure; but the latter alone, according to Prof. Kolliker, contain muscular fibre-cells. These tubes divide and subdivide, like the branches of a tree, still retaining their ordinary characters, until they are no more than from 1-50th to 1-30th of an inch in diameter; and in these the longitudinal and annular fibres, together with the ciliated epithelium, come to an abrupt termination. At a short distance from this point (*a*, Fig. 67) each tube terminates in a slight dilatation (*b*), into which open a number of orifices leading into somewhat elongated cavities (*c*) termed by Dr. Waters† "Air-sacs." From six to eight or ten of these sacs are clustered round the extremity of every bronchial tube: they possess exceedingly delicate walls, and do not appear to communicate with one another, otherwise than by their common origin from the bronchial tube.‡ They

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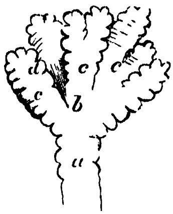
* For an account of the principal forms of Respiratory apparatus among the lower Animals, see "PRINC. OF COMP. PHYS." chap. vi.; also the Memoir by Mr. Rainey in the "Med.-Chirurg. Trans.," vol. xxviii.; and Prof. Kolliker's "Manual of Human Microscopic Anatomy," 1860, Lond. For excellent general accounts of the structure of the Human Lung, see Waters's "Fothergillian Essay," London, 1860; and Williams in the Supplement of the "Cycl. Anat. and Physiology."

† "The Human Lung," Fothergillian Prize Essay, 1860, p. 133 *et seq.*

‡ According to Dr. Williams, however, the passages corresponding to Dr. Waters's air-sacs intercommunicate freely with one another, though not with those springing from other bronchial tubes.

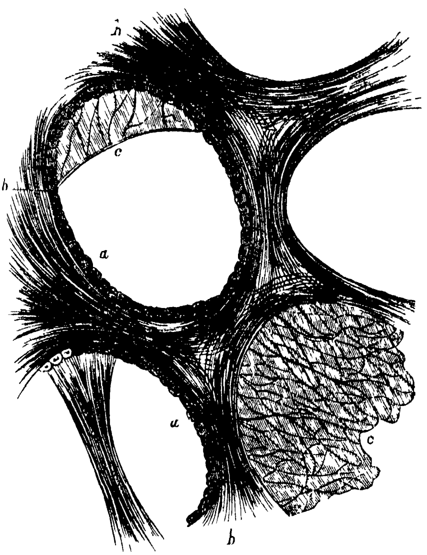
generally increase slightly in size towards their closed extremity, and often bifurcate. The internal surface of every sac, and even of the bronchial tube for a short distance before it terminates, presents an alveolated or honeycombed appearance. These minute depressions (*d*) constitute the Air-vesicles of the Lung, and from ten to twenty may be counted on the interior of each air-sac.

FIG. 67.



262. The walls of the air-vesicles are formed of a very thin and transparent membrane (Fig. 68, *c*), which is folded sharply at the orifices of communication, so as to form a very definite border to them; and which is lined by an epithelial layer (*a*),* composed of minute polygonal cells of from 1-1600th to 1-2250th of an inch in diameter, and from 1-2800th to 1-3800th of an inch in thickness. Between the air-vesicles is a kind of trabecular tissue, which seems to be almost entirely composed of yellow elastic fibres (*b*); and some of these fibres also coalesce with the lining membrane, so as to impart to it increased strength; this being especially the case around the apertures of communication between the contiguous air-cells. It is only between the lobular groups of air-vesicles that connective tissue exists in any appreciable quantity.—The diameter of the Human air-cells is about twenty times greater than that of the capillaries which are distributed upon their parietes; varying (according to the measurement of Weber) from the 1-200th to the 1-70th of an inch.† The capillary plexus (Fig. 69) is so disposed between the two layers which form the walls of two adjacent air-cells, as to expose one of its surfaces to each; by which provision the full influence of the air upon it is secured. The net-

FIG. 68.



Air-cells of *Human Lung*, with intervening tissues:—*a*, epithelium; *b*, elastic trabeculæ; *c*, membranous wall, with fine elastic fibres.

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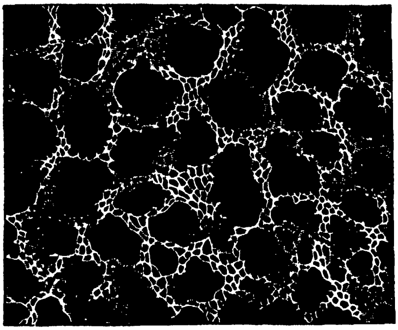
* The presence of this layer of epithelium has been much contested, and many eminent authorities may be cited on both sides. See Zenker ("Beitrage zur Anatomie der Lunge," Dresden. 1862, p. 11), who positively denies its existence.

† The dimensions given by Moleschott ("De Vesiculis Pulmonum Malpighianis") are very much less than these; the range of diameter being stated by him at between 1-120th and 1-1200th of an inch. The Author's own observations, however, lead him to regard Weber's statement as very near the truth; and that of Prof. Kolliker is almost precisely the same.

work of vessels is so close, that the diameter of the meshes is scarcely so great as that of the capillaries which enclose them; indeed it would be impossible to conceive of a method, by which blood, whilst still retained within vessels, should be spread over a larger surface for aeration. And if not restricted within vessels, it could not be ceaselessly and rapidly driven-on by the propulsive power of the heart, which acts no less efficiently upon the pulmonary circulation than upon the systemic, although the force exerted is much inferior, the resisting power being far less, in consequence of the shortness of the circuit.

FIG. 69.



Arrangement of the Capillaries of the air-cells of the *Human Lung*.

263. The fibrous coat of the bronchial tubes possesses a considerable amount of muscular contractility, which (according to the experiments of Dr. C. J. B. Williams*) may be excited by electrical, chemical, or mechanical stimuli, applied to themselves. This contractility resembles that of the intestines or arteries, more than that of the voluntary muscles or heart; the contraction and relaxation being more gradual than that of the latter, though less tardy than that of the former. It is chiefly manifested in the smaller bronchial tubes, those of less than a line in diameter having been seen to contract gradually under the stimulus of galvanism, until their cavity was nearly obliterated; on the other hand, in the trachea and the larger bronchi, the cartilaginous rings prevent any decided diminution in the calibre of the tubes, and the muscular structure is much less distinct. It is doubtful whether the contractility can be called into play by irritation of the Pneumogastrics; Volkmann† and Longet‡ affirming that it can, whilst Rosenthal§ and Rügenberg|| maintain that if a manometer be inserted into the trachea, irritation of the peripheric extremity of the Vagus never produces any increase of pressure, which would certainly occur if the capacity of the bronchi diminished. It is remarked by Dr. Williams, that the contractility of the bronchial muscles is soon exhausted by direct stimulation; but that it may in some degree be restored by rest, even when the lung is removed from the body. When the stimulation is long continued, however, as by intense irritation of the mucous membrane during life, the contractile tissue passes into a state which resembles the tonic contraction of muscular fibre. The contractility is greatly affected by the mode of death, and is remarkably diminished by the action of vegetable narcotics, particularly stramonium and belladonna; whilst it seems to be scarcely at all affected

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* "Report of the British Association for 1840," p. 411.

† "Wagner's Handwörterbuch," band ii., Art. 'Nervenphysiologie,' p. 586.

‡ "Anat. et Physiol. du Système Nerveux," tom. ii. p. 289.

§ "Die Athembewegungen," p. 232.

|| "Studien des Phys. Institut zu Breslau," 1863, p. 47.

by hydrocyanic acid.—These facts are very important, as throwing light upon certain diseased conditions. It has long been suspected, that the dyspnœa of Spasmodic Asthma depends upon a constricted state of the smaller bronchial tubes, excited through the nervous system, frequently by a stimulating cause at some distance; and there can be now little doubt that such is the case. The peculiar influence of stramonium and belladonna, in diminishing the contractility of these fibres, harmonises remarkably with the well-known fact of the relief frequently afforded by them in this distressing malady. It seems not improbable that this contractility of the bronchial tubes may serve to regulate the supply of air to the lobules, in accordance with the wants of the system, just as the contractility of the minute arteries regulates the supply of blood to the organs to which they proceed; and it may possibly be through this channel, that the remarkable variation is effected in the amount of respiration, which adapts the quantity of heat produced to the depression of the external temperature (§ 259). It has been further suggested by Dr. W. T. Gairdner,* that the contractility of the smaller bronchi may serve to expel collections of mucus which have accumulated in them, and which neither ciliary action nor the ordinary expiratory efforts suffice to displace.†

264. Although there is no sufficient reason to believe that the Lungs are possessed of any power of vital contractility, yet their Elasticity prevents them from being altogether passive agents in the respiratory operation. The elastic tension is rapidly increased by the dilatation of the lungs with air;‡ and the carefully-conducted experiments of Dr. Hutchinson§ lead him to estimate it at certainly not less than ½ lb. upon each square inch of surface, when the lungs have been filled by the deepest possible inspiration; so that its whole amount (reckoning an average surface of 300 sq. in. for the male, and 247 sq. in. for the female) will be not less than 150 lbs. for the male, and 123½ lbs. for the female. This force is exerted in aid of the *ex*piratory movement, and is directly antagonistic to the *in*spiratory; so that the inspiratory muscles must overcome it, in order to produce complete distension of the pulmonary cavities. This distension is entirely accomplished by the action of the muscles external to the thorax, or partly forming its parietes.

265. The mechanism of the respiratory acts may be rendered clearly intelligible by the accompanying diagram, in which the trachea and lungs (5, 6, Fig. 70) are enclosed in a glass vessel with three openings. The lower opening (2) is closed by a bladder or piece of caoutchouc, representing the diaphragm, and capable of being either pushed into the cavity of the vessel or of being drawn down by a weight. The upper opening is closed by a

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* "Edinburgh Monthly Journal," May, 1851.

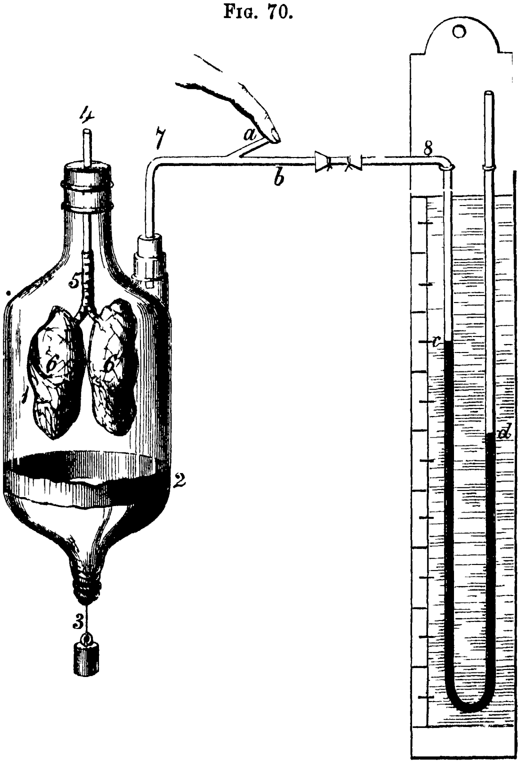
† It has been maintained by Dr. Radclyffe Hall ("Transactions of Provincial Medical Association," 1850), that the contractility of the bronchial tubes is called into action in each expiratory movement, to assist in emptying the lungs. But no evidence has been adduced in support of this doctrine; and its improbability is apparent from the obvious fact, that a contraction of the air-tubes would impede, rather than promote, the emptying of the air-vesicles.

‡ Donders estimates the expiratory force derived from the elasticity and muscular tension of the Lungs, and coming into play in ordinary respiration, as equal to a column of mercury about 1-3rd of an inch in height. See his Essays in Henle and Pfeuffer's "Zeitsch.," band iii. and iv.

§ "Cyclopædia of Anatomy," Art. 'Thorax,' vol. iv. p. 1058.

cork, through which a glass tube (4), firmly attached to the trachea, passes. The lateral opening (7) is connected with a manometer (*c*, *d*) by a tube (*b*), having a small lateral branch (*a*) opening to the air. If the openings (*a* and 4) be now stopped whilst the bladder is extended by the weight (3), the rarefaction of the air in the glass vessel will be made apparent by the rise of the mercury in the arm (*c*) of the manometer. It is obvious that the pressure of the air within and without the lungs will be different, and consequently, on opening the orifice of the tube (4) air

FIG. 70.



Apparatus constructed by Donders to show the Mechanism of the Respiration

will rush through it and the trachea to equalize the pressure as far as the elasticity of the lung will permit. Such, with the exception that in the living body no air intervenes between the surface of the lung and the walls of the thorax, and therefore no rarefaction, but only a tendency to a vacuum occurs, are the conditions present in the ordinary act of inspiration. On the contrary, with the same exception, the act of expiration may be imitated by pushing the bladder into the vessel; for then the pressure on the exterior of the lungs will be increased, the mercury in the arm (*c*) of the manometer will descend, and, aided by their own elasticity, the lungs will contract upon and drive out the air contained within their cavities.

266. The complete dependence of the expansion of the Lungs upon the enlargement of the cavity of the chest, is well shown by the effect of admission of air into the pleural cavity. When an aperture is made on either side (as by removing the finger from the orifice of the tube *a* in the apparatus represented in Fig. 70), so that the air rushes-in at each inspiratory movement, the expansion of the lung on that side is diminished, or entirely prevented, in proportion to the size of the aperture. If air can enter through it more readily than through the trachea, an entire collapse of the lung takes place; and by making such an aperture on each side, complete asphyxia is produced. But if it be too small to admit the very ready passage of air, the vacuum produced by the inspiratory movement is more easily filled by the distension of the lungs, than by the rush of air into the pleural cavity; so that a sufficient amount of change takes place for the maintenance of life. This is frequently observed in the case of penetrating wounds of the thorax, in the surgical treatment of which it is of great importance to close the aperture as completely as possible; when this has been accomplished, the air that had found its way into the cavity is soon absorbed, and the lung resumes its full play. Where one lung is obstructed by tubercular deposit, or is prevented in any other way from rightly discharging its function, an opening that freely admits air into the pleural cavity of the other side is necessarily attended with an immediately-fatal result; and in this manner it not unfrequently happens that chronic pulmonary diseases suddenly terminate in Asphyxia, a communication being opened by ulceration between a bronchial tube and the cavity of the thorax.

267. *Of the Respiratory Movements.*—Every complete act of respiration may be divided into—1, Inspiration; 2, Pause, often absent and always of short duration; 3, Expiration; 4, Pause, which according to Vierordt* is about equal to one-fifth of the entire period occupied by each act of respiration. Sibson, Vierordt, and others have established experimentally that the duration of the inspiration is to that of expiration as 10 : 14 in the child, female, and old person; and as 10 : 12 in the adult male. In ordinary tranquil breathing (especially in children), the action of the diaphragm is alone nearly sufficient to produce the necessary exchange of air; but, when a full inspiration is required, the cavity of the chest is dilated laterally and antero-posteriorly, as well as inferiorly. The enlargement of the chest in both these directions is effected by the elevation of the ribs; for whilst, in the undilated state of the thorax, the ribs form an angle with their cartilages, which become less and less obtuse as we pass from the first rib downwards, the elevation of the ribs tends to bring them and their cartilages more nearly into a line, and thus separates them more widely from the median plane, and at the same time causes them to push forwards the sternum. Owing to the greater length of the lower true ribs, and the greater obliquity of their junction with their cartilages, both these changes are more considerable in the lower part of the thorax than in the upper; and this is especially the case in adult men, whose respiration has been designated as 'inferior costal,' whilst in females the

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* "Physiologie," p. 156.

mobility of the first rib and of the whole of the upper part of the thorax is greater, so that their respiration may be designated as 'superior costal.'—The thoracic muscles whose contraction participates in the ordinary movements of Inspiration, are, according to Dr. Hutchinson,* the *external* intercostal, with those portions of the internal intercostals which pass between the cartilages, the levatores costarum, and a portion of the triangularis sterni, all of which have the same action, that of elevating the ribs. On the other hand, the thoracic Expiratory muscles are the proper costal portion of the *internal* intercostals, with the infracostals, and a part of the triangularis sterni. The expiratory movement will be assisted also by the abdominal muscles, which antagonize the diaphragm by pressing-back the abdominal viscera, and thus causing its ascent so soon as it has become relaxed. There are many accessory muscles, however, which take a share in violent respiratory movements, both inspiratory and expiratory. Thus all the muscles which elevate the scapula, may act through it upon the ribs, and the scaleni act directly upon the first rib; whilst all those which erect the spine, fix more perfectly the origins of these and other muscles which are to act upon the thorax. So, again, the expiratory movement is aided by the longissimus dorsi, sacro-lumbalis, and other muscles which tend to depress the ribs. In difficult respiration, almost every muscle in the body is made in some way subservient to the distension of the chest; thus, a patient suffering under urgent dyspnœa instinctively lays hold of some fixed object, so as to prevent his upper extremities from moving; and thus his scapula becomes a fixed point, from which the pectorales (major and minor) and serratus magnus can aid in elevating the ribs.

268. The relative amount of muscular force which is required for these two movements respectively, is affected in a very remarkable manner by the elasticity of the walls of the thoracic cavity; for this (like the elasticity of the lungs) supplies a force which greatly aids the *ex*piratory movement, whilst it offers a corresponding opposition to the *in*spiratory. Here, also, the degree of force exerted increases very rapidly with the degree of distension. Thus in a body experimented-on by Dr. Hutchinson,† the following were the relations between the amount of air forced-in, the resisting elasticity, as shown by the height of mercury supported, the actual pressure upon each square inch of surface which this indicated, and the total pressure over the surface of the chest, reckoning its area at 206 square inches:—

	Cubic inches.			*Pressure in height of Mercury.*	*Pressure per sq. in.*	*Total Pressure.*
Air forced in	70	Resisting	elasticity	1·00 inch.	7·8 oz.	104·4 lbs.
,,	90	,,	,,	1·50 ,,	11·7 ,,	150·6 ,,
,,	180	,,	,,	3.25 ,,	25·3 ,,	326·3 ,,
,,	200	,,	,,	4·50 ,,	35·1 ,,	451·9 ,,

To this 451·9 lbs. must be added at least 128 lbs. for the elastic force of the lungs themselves at that degree of distension, making altogether 580 lbs.; and as the subject of this observation could expire during life considerably more air than the highest amount forced into his chest after death, there can be little doubt (judging from the rapid ratio in which the elastic force increases when the distension is approaching its limits) that the muscular power required to overcome this, towards the close of a very deep inspiration, could not have been less than 1000 lbs. The co-operation of the elastic resistance with the expiratory movement, and its antagonism to the inspiratory, is doubtless the principal cause why the power of the expiratory muscles, as tested by the height of the column of mercury supported by the air, should always be greater than that of the inspiratory muscles;* and why the expiratory power should be very much greater when the chest has been well filled with air, than when it is comparatively empty. The following is given by Dr. Hutchinson as the range through which these powers may vary within the limits of health:—

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* Op. cit., p. 1055.

† Op. cit., p. 1056.

Power of Inspiratory Muscles.		*Power of Expiratory Muscles.*
1·5 inch.	Weak	2·0 inches.
2·0 „	Ordinary	2·5 „
4·5 „	Remarkable	5·8 „
7·0 „	Very extraordinary	10·0 „

The expiratory power may be augmented by the habitual performance of movements in which they participate; and thus the inspiratory power is the preferable test of the *vis vitæ.* This has been found by Dr. Hutchinson to bear some relation to height, being greatest (on an average of a considerable number of cases) when the stature is 5 feet 7 or 8 inches; and diminishing above that height, as well as below it.

269. It is impossible to form a correct estimate, by observations on one's-self, of the usual number and extent of the respiratory movements; since the direction of the attention to them is certain to increase their frequency and amount. In general it may be stated, that from 16 to 20 alternations usually occur in a minute;† of these, the ordinary inspirations involve but little movement of the thorax; but a greater exertion is made at about every fifth recurrence. According to Quetelet, the infant at birth breathes—

	44	times per minute.
At 5 years of age	26	„
„ 15 to 20	20	„
„ 20 „ 25	18·7	„
„ 25 „ 30	16	„
„ 30 „ 50	18·1	„

The average numerical proportion of the respiratory movements to the pulsations of the heart, is about 1 : 5, 1 : 4½, or 1 : 4; and when this proportion is widely departed-from, there is reason to suspect some obstruction to the aeration of the blood, or some disorder of the nervous system.‡

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* See Dr. Hutchinson, Op. cit., p. 1061.

† See Dr. Hutchinson's Table, in "Cyclop. of Anat. and Phys.," vol. iv. p. 1085.

‡ v. Ghert has shown that, during violent exertion, the respirations increase in frequency more than the pulsations; but that in the subsequent period of rest, the increased activity of the cardiac movements is more persistent than that of the respiratory. Donders ("Physiol.," 2 Aufl. band i. § 128) and Moleschott and Moriggia have experimentally proved, that though there is generally a close connection in the rhythmical performance of these two acts, yet that this is by no means necessary or constant, for it was possible to obtain, on irritation of the centric extremities of the cut Vagi, an increase in the number of pulsations, with a stoppage of the diaphragm, either in expiration or inspiration, or, *vice versâ*, diminution of the pulse and acceleration of the breathing: effects which they attempt to explain on the supposition that the irritation, carried to the Vagal Centrum, is reflected downwards, either through the Phrenics upon the Diaphragm, or through the Cardiac nerves, upon the Heart, sometimes calling one and sometimes the other chiefly into play. (Moleschott's "Unters.," band ix. 1863, p. 172.)

Thus in Pneumonia, in which a greater or less amount of the lung is unfit for its office, the number of respirations increases in a more rapid proportion than the acceleration of the pulse; so that the ratio becomes as 1 to 3, or even 1 to 2, in accordance with the degree of engorgement.* In Hysterical patients, however, a similar increase, or even a greater one, may take place without any serious cause; thus Dr. Elliotson† mentions a case in which the respiratory movements of a young female, through nervous affection, were 98 or even 106, whilst the pulse was 104. On the other hand, the respiration in certain typhoid conditions and in narcotic poisoning becomes abnormally slow, owing to the torpid condition of the nervous centres, the proportion being 1 to 6, or even 1 to 8; and in such cases, the lungs not unfrequently become œdematous, from a cause hereafter to be mentioned (§ 281).

270. Not only the rate of the Respiratory movements, but also their extent, is affected by various morbid conditions; thus when dislocation of the spine takes place above the origin of the intercostal nerves, but below that of the phrenic, so that the former are paralysed, the respiratory movement is confined to the diaphragm: and as this is insufficient, serum is effused into the lungs, and a slow Asphyxia supervenes, which usually proves fatal in from three to seven days. Even where the muscles and nerves are all capable of action, the full performance of the inspiratory movements is prevented by the solidification or engorgement of any part of the lung, which interferes with its free distension; or by adhesions between the pleural surfaces, which offer a still more direct impediment. When these adhesions are of long standing, they are commonly stretched into bands, by the continual tension to which they are subjected. If the impeding cause affect both sides, the movements of both will be alike interfered-with; but if one side only be affected, its movements will be diminished, whilst those of the other remain natural; and the physician hence frequently derives an indication of great value, in regard to the degree in which the lung has become incapable of performing its functions. It is to be remembered, however, that the action both of the diaphragm and of the elevators of the ribs may be prevented, by pain either in the muscles themselves or in the parts which they move; thus the descent of the diaphragm is checked by inflammation of the abdominal viscera or of the peritoneum; and the play of the intercostals by rheumatism, pleuritis, pericarditis, or other painful disorders of the parts forming the parietes of the thorax.

271. We have now to inquire into the mode in which the Muscular movements of Respiration are kept-up by nervous power.—There can be no doubt that these movements, though partly under the control of the Will, are essentially 'automatic' in their nature. Their chief centres consist of two ganglia placed on either side of the point of the Calamus Scriptorius, and connected by a grey commissure:‡ corresponding there-

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* See a Paper by Dr. Hooker, on the 'Relation between the Respiratory and Circulating Functions,' in the "Boston (N.E.) Medical and Surgical Journal;" an abstract of which will be found in the "British and Foreign Medical Review," vol. iv. p. 263.

† "Physiology," p. 215, *note*.

‡ See Longet ("Physiologie," 1861, vol. ii. p. 396), Flourens ("Comptes Rendus," 1851, p. 437, and 1858), Brown-Séquard ("Journal de la Physiologie," vol. i. 1858, p. 232), Schiff ("Physiologie," 1859, p. 323).

fore to the origins of the Pneumogastric Nerves, which are the principal excitor nerves that convey the stimulus on which the movements are dependent, whilst from the adjacent parts of the Medulla Oblongata and Spinalis proceed the chief motor nerves by which they are carried into effect. And thus it happens that the whole of the Encephalon may be removed from above, and the Spinal cord (as far up as the origin of the phrenic nerve) from below, without suspending the most essential of the respiratory movements. But other parts of the automatic centres are concerned in the ordinary movements of respiration; and there is probably no part that may not be excited to action, by the extraordinary stimulus which results from a prolonged interruption to the aeration of the blood (§ 267).

272. The chief "excitor" of the respiratory movements is unquestionably the Pneumogastric Nerve. But as the movements of respiration consist of an inspiratory and an expiratory act, each of which may be induced by its appropriate stimulus, so it appears that a double function is attributable to these nerves; and that whilst irritation of their pulmonary branches leads to contraction of the diaphragm, and therefore to an act of inspiration, irritation of the sensory branches of the superior laryngeal nerve induces relaxation of the diaphragm and contraction of the expiratory muscles, as may be observed in the energetic act of expiration produced by the contact of a foreign body with the extremely sensitive lining membrane of the Larynx.—The effects of section of the Vagi appear to differ considerably in different animals. When made on one side, the effects are not constant;* but when the nerves are divided on both sides, according to the experiments of Dr. J. Reid,† the number of respiratory movements in dogs is considerably diminished, usually by about one-half. Rosenthal‡ found that after double section in pigeons the frequency of the respirations fell in the proportion of 8 : 1. The depth of each inspiration increased, however, as 1 : 2·5; the respiratory activity, therefore, was altogether diminished to about one-third of its original amount. The effect of the double section in rabbits was found both by Rosenthal and Gilchrist to be uncertain, though generally speaking there was no material alteration; the diminution in the frequency of the acts being compensated for by a proportionate increase in the depth of each inspiration, which at the same time assumed a sudden and spasmodic character, with long intervening pauses. The trunks of the Pneumogastric Nerves are not endowed with much sensibility; for if pinched or pricked, the animal does not exhibit nearly such acute signs of pain as when the trunks of the ordinary spinal nerves or of the Fifth pair are subjected to similar treatment. The effects of the application of a feeble electrical stimulus to the central end of a divided Pneumogastric nerve was observed by Rosenthal to be followed by slight acceleration of the respiratory movements,—in effecting which, both the inspiratory and expiratory muscles participated; but if the stimulus were increased in strength, tetanus of the diaphragm supervened, followed, when the nerve was exhausted, either by complete relaxation of the muscle, or by a kind of vibratory movement in its fibres.

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* Gilchrist, "Med.-Chir. Rev.," 1858, vol. ii. p. 495.

† "Edinb. Med. and Surg. Journ.," vol. li.; and "Phys., Anat., and Pathol. Res.," p. 177.

‡ "Comptes Rendus," 1861, p. 754.

273. The stimulus to the excitor activity of the pulmonary branches of the Pneumogastric nerves, has generally been considered to be the presence of venous blood in the capillaries of the lungs, or of carbonic acid in the air-cells (Marshall Hall); but the experiments of Traube appear to show that the proportion of carbonic acid in the blood has no direct influence on the number of the respiratory movements, since it may become greatly diminished without causing them to become feeble; whilst, according to Regnault and Reiset, it may rise to an unusually high percentage without making them more energetic. Hence it would appear that it is the deficiency of oxygen, rather than the presence of carbonic acid, which is to be regarded as the true stimulus to the respiratory movements; for the respiratory movements become weaker in proportion as there is more oxygen in the blood, and they cease altogether when the proportion rises to a certain amount. On the contrary, with the diminution of oxygen in the blood the respiratory movements become stronger, provided that the function of the respiratory centres is not too seriously impaired.

274. But why (it may be asked) do the movements continue, when the Pneumogastrics have been divided, and the Encephalon has been removed? It is evident that there must be *other* excitors to the action of the respiratory muscles. Amongst these, the nerves distributed to the general surface, and particularly to the face, probably perform an important part; and in exciting the first inspiration, the Fifth pair seems the principal agent. It has long been a well-known fact, that the first inspiratory effort of the new-born infant is most vigorously performed when the cool external air comes into contact with the face; and that impressions on the general surface, such as a slap of the hand on the nates, are often effectual in exciting the first inspiratory movements, when they would not otherwise commence. Dr. M. Hall relates an interesting case, in which the first inspiration was delayed, simply because the face was protected by the bed-clothes from the atmosphere;* and, on lifting-up these, the infant immediately breathed. Dr. M. Hall has also mentioned the important fact, that although, if the cerebrum be removed, and the pneumogastrics divided, in a young kitten, the number of acts of respiration will be reduced to four in a minute, yet by directing a stream of air on the animal, or by irritating various parts of the general surface, we may excite twenty or thirty acts of respiration within the same space of time. He further remarks that in the very young warm-blooded animal, as in the cold-blooded animal, the phenomena of the excito-motor power are far more vividly manifested than in the older and warm-blooded. In the very young kitten, even when asphyxiated to insensibility, every touch, contact, or slight blow, every jar of the table, any sudden impression of the external air, or that of a few drops of cold water, induces at once energetic reflex movements and acts of inspiration. This may be looked upon as Nature's provision for the first establishment of the respiratory function in the new-born animal.—But the influence of the nerves of the general system is by no means wanting in the adult; as many familiar facts demonstrate. Thus every one knows that the first plunge into cold water, or the first descent of the streams of the

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* "New Memoir on the True Spinal Marrow," &c., p. 29.

shower-bath, or even the dashing of a glass of cold water in the face, will produce inspiratory efforts; and this fact has many important practical applications. Thus in the treatment of Asphyxia, whether congenital, or the result of narcotic poisoning, drowning, &c., the alternate application of cold and heat is found to be one of the most efficacious means of restoring the respiratory movements; and a paroxysm of hysteric laughter may be cut-short by dashing a glass of cold water in the face. One of Dr. Reid's experiments strikingly demonstrates the variety of the provisions that have been made for the performance of this function. After dividing the pneumogastrics, and removing the cerebrum and cerebellum, he divided the spinal cord high-up in the neck, so as to cut-off the communication between the spinal nerves and the Medulla Oblongata; and he found that the frequency of the respiratory movements was still further diminished, although they were not even then entirely suspended; their continuance, after every channel of excitation appeared to have been cut off, being probably dependent (as he himself suggested) on the circulation of imperfectly-aerated blood in the Medulla Oblongata. M. Brown-Séquard* has lately paid particular attention to the rhythmical movements of the Diaphragm in Rabbits, which are observed to occur after section of the phrenic nerves, and even after destruction of the entire Spinal Cord. He attributes them to the minute ganglia, described by Rouget, which are found on the filaments of the Phrenic nerve. It is very remarkable that after such serious injury to the nervous system, the two sides of the Diaphragm, which are chiefly connected by tendon, should act synchronously; and also that the inspiratory movements of the Diaphragm should regularly alternate with those of the expiratory muscles, which in Rabbits are chiefly the external oblique muscles of the abdomen.—It seems not improbable that even the Sympathetic nerve, which derives many filaments from the Cerebro-Spinal system, and which especially communicates with the Pneumogastric nerves, may be one of the excitors to this function; and this, perhaps, not only through its ramifications in the lungs, which are considerable, but also by its distribution on the systemic vessels; so that it may convey to the Spinal Cord the impression of imperfectly-arterialized blood circulating through these, such as the Pneumogastric is believed to transmit from the lungs.

275. The motor or 'efferent' nerves concerned in the function of Respiration, are those which Sir C. Bell has grouped-together in his 'respiratory system.' The most important of these, the Phrenic, arises from the upper part of the Spinal Cord; the Intercostals much lower down; whilst the Facial nerve and the Spinal Accessory, to the latter of which, as will be shown hereafter (CHAP. XI. Sect. 2), the motor powers of the Pneumogastric are chiefly due, take their origin in the Medulla Oblongata itself.

276. That the respiratory movements, as ordinarily performed, are essentially independent of the Will, appears not only from our own consciousness, but also from cases of paralysis; in some of which the power of the will over the muscles has been lost, whilst the movements have been kept-up by the reflex action of the Medulla Oblongata or respiratory ganglion; whilst in others, some of the respiratory muscles have been

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* "Journ. de la Physiol.," t. ii. p. 115.

motionless during ordinary breathing, and yet have remained under the power of the will.* That consciousness is not a necessary link in the chain of causes which produce the respiratory movements, we are enabled to judge from the phenomena presented by the human being in sleep and coma, by anencephalous fœtuses, and by decapitated animals. This conclusion is confirmed by a case recorded by Dr. H. Ley,† who had under his care a patient in whom the pneumogastrics appeared to be diseased; the lungs suffered in the usual way in consequence, and the patient had evidently laborious breathing; but he distinctly said that he felt no uneasiness in his chest.—The experience of every one informs him, however, that the Respiratory movements are partly under the control of the will, though frequently unrestrainable by it. In ordinary circumstances, when the blood is being perfectly aerated, and there is a sufficient amount of arterial blood in the system to carry-on the functions of life for a short time, we can suspend the respiratory actions during a few seconds without any inconvenience. If, however, we endeavour to prolong the suspension, the stimulus conveyed by the excitor nerves to the Medulla Oblongata becomes too strong, and we cannot avoid making inspiratory efforts; and if the suspension be still further prolonged, the whole body becomes agitated by movements which are almost of a convulsive nature, and no effort of the will can then prevent the ingress of air.‡ It is easy to understand why, in the higher animals at least, and more especially in Man, the respiratory actions should be thus placed under the direction of the will: since they are subservient to the production of those Sounds, by which individuals communicate their feelings and desires to each other; and which, when articulate, are capable of so completely expressing what is passing in the mind of the speaker.

277. The motor power of the Respiratory nerves is exercised, however, not only on the muscles which perform the inspiratory and expiratory movements, but on those which guard the entrance to the windpipe, and also on some other parts. Between the superior and inferior Laryngeal nerves there is an important difference, which anatomical and experimental research has now very clearly demonstrated. It appears from the very careful and satisfactory observations and experiments of Dr. J. Reid,§ that, whilst the *inferior* laryngeal is the *motor* nerve of nearly all the laryngeal muscles, the *superior* laryngeal is an *afferent* nerve of extreme sensibility, conveying to the Medulla Oblongata the impressions made on its peripheral extremities. The motor endowments of the latter are limited to the crico-thyroid muscle, to which alone of all the muscles its filaments can be traced, the remainder being distributed beneath the

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* Such cases are mentioned by Sir C. Bell, in the Appendix to his work on the "Nervous System of the Human Body."

† "On Laryngismus Stridulus," p. 417.

‡ It is asserted by M. Bourdon ("Recherches sur le Mécanisme de la Respiration," p. 21), that no person ever committed suicide, though many have attempted to do so, by simply holding the breath; the control of the will over the respiratory muscles not being sufficiently great to antagonize the stimulus of the "besoin de respirer," when this has become aggravated by the temporary cessation of the action. But such persons have succeeded better by holding the face beneath the surface of water; because here another set of muscles is called into action, which are much more under the control of the will than are those of respiration; and a strong volition applied to these can prevent all access of air to the lungs, however violent may be the inspiratory efforts.

§ "Edinb. Med. and Surg. Journ.," Jan. 1838; and "Anat., Physiol., and Pathol. Res.," chap. iv.

mucous surface of the larynx; and its sensibility is very evident, when it is pinched or irritated during experiments upon it. On the other hand, the motor character of the inferior laryngeal branch is shown by its very slight sensibility to injury, by its nearly exclusive distribution to muscles, and by its influence in exciting contraction of these when its separated trunk is stimulated.

278. It was also ascertained by Dr. J. Reid,* that, if the inferior laryngeal branches be divided, or the trunk of the pneumogastric be cut above their origin from it, no constriction of the glottis follows, but a paralysed state of its muscles. After the first paroxysm occasioned by the operation, a period of quiescence and freedom from dyspnœa often supervenes, the respirations being performed with ease so long as the animal remains at rest; but an unusual respiratory movement, such as takes place at the commencement of a struggle, induces immediate symptoms of suffocation,—the current of air carrying inwards the arytenoid cartilages, which are rendered passive by the paralysed state of their muscles; and these, falling upon the opening of the glottis, like valves, obstruct the entrance of air into the lungs. The more effort is made, the greater will be the obstruction: and accordingly, it is generally necessary to counteract the tendency to suffocation, when it is desired to prolong the life of the animal after this operation, by making an opening into the trachea. Dr. Reid further ascertained, that the application of a stimulus to the inferior laryngeal nerves, when separated from the trunk, would occasion distinct muscular contractions in the larynx; whilst a corresponding stimulus applied to the superior laryngeal occasioned no muscular movement, except in the crico-thyroid muscle. But when the superior laryngeals were entire, irritation of the mucous surface of the larynx, or of the trunks themselves, produced contraction of the glottis and efforts to cough; effects which were at once prevented by dividing those nerves, and thereby cutting-off their communication with the Medulla Oblongata. The observations of Dr. Reid have been fully corroborated by those of Rosenthal,† who found in addition, that, if the superior laryngeal nerves were carefully isolated and stimulated with weak induction currents, the respirations fell in frequency, chiefly in consequence of the prolongation of the pause; and if the strength of the current were somewhat increased, complete *relaxation of the diaphragm* occurred. The strength of the current to produce these effects must, however, be much less considerable than is required to produce increase of respiratory activity and tetanus of the diaphragm, when applied to the trunk of the Pneumogastric, on account of the extreme sensibility of the superior laryngeal nerve. The inhibitory influence upon the respiratory function, and especially upon the movements of the diaphragm, thus attributed by Rosenthal to the superior laryngeal branches of the Pneumogastric nerve, is so far different from that of the Cardiac and Splanchnic branches of the same nerve—whose controlling power over muscular movements has been already alluded to—that it acts centripetally on the Medulla Oblongata, and not, like them, centrifugally. There can be no doubt, then, that the superior and inferior laryngeal branches constitute the circle of incident and motor nerves, by

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* Op. cit.

† Rosenthal, "Die Athembewegungen und ihren Beziehungen zum Nerv. Vagus," Berlin, 1862; and "Archiv f. Anat. und Physiol.," 1862, p. 226.

which the aperture of the glottis is governed, and by which any irritation of the larynx is made to close the passage, so as to prevent the entrance of improper substances; whilst the superior laryngeal nerve also excites the muscles of expiration, so as to cause the violent ejection of a blast of air, by which the offending gas, fluid, or solid, may be carried-off. The effect of carbonic acid in causing spasmodic closure of the glottis is well known; and affords a beautiful example of the protective office of this system of nerves.—The mucous surface of the trachea and bronchi appears, from the experiments of Valentin, to be endowed with excitability, so that stimuli applied to it produce expiratory movements; and this evidently operates through the branches of the pneumogastric distributed upon the membrane. Here, as elsewhere, we find that a stimulus applied to the *surface* has a much more decided influence, than irritation of the *trunk* of the nerve supplying it.

279. The actions of *sighing*, *yawning*, *sobbing*, *laughing*, *coughing*, and *sneezing*, are nothing else than simple modifications of the ordinary movements of respiration, excited either by mental emotions, or by some stimulus originating in the respiratory organs themselves.—*Sighing* is nothing more than a very long-drawn inspiration, in which a larger quantity of air than usual is made to enter the lungs. This is continually taking place to a moderate degree; and we notice it particularly when the attention is released, after having been fixed upon an object which has excited it strongly, and which has prevented our feeling the insufficiency of the ordinary movements of respiration. Hence this action is only occasionally connected with mental emotion.—*Yawning* is a still deeper inspiration, which is accompanied by a kind of spasmodic contraction of the depressors of the lower jaw, and also by a very great elevation of the ribs, in which the scapulæ partake. The purely voluntary character of this movement is sometimes seen, in a remarkable manner, in cases of palsy; in which the patient cannot raise his shoulder by an effort of the will, but does so in the act of yawning. Nevertheless this act may be performed by the will, though not completely; and it is one that is particularly excited by an involuntary tendency to imitation, as every one must have experienced who has ever been in company with a set of yawners.—*Sobbing* is the consequence of a series of short convulsive contractions of the diaphragm; and it is usually accompanied by a closure of the glottis, so that no air really enters.—In *Hiccup*, the same convulsive respiratory movement occurs, and the glottis closes suddenly in the midst of it; the sound is occasioned by the impulse of the column of air in motion against the glottis.—In *Laughing*, a precisely reverse action takes place; the muscles of expiration are in convulsive movement, more or less violent, and send-out the breath in a series of jerks, the glottis being open. This sometimes goes-on, until the diaphragm is more arched, and the chest is more completely emptied of air, than it could be by an ordinary movement of expiration.—The act of *Crying*, though occasioned by a contrary emotion, is, so far as the respiration is concerned, very nearly the same as the last. Every one knows the effect of mixed emotions, in producing an expression of them which is "between a laugh and a cry."—The greater part of the preceding movements seem to belong as much to the *consensual* or to the *emotional*, as to the *excito-motor* group of actions; for whilst they are sometimes the result

of peculiar states of the respiratory organs, or of the bodily system in general, they may also be called-forth by influences which operate directly through the senses, or which excite the emotions. Thus, whilst Sighing and Yawning often occur as simple results of deficient aeration, they may be brought-on,—the former by a depressed state of the feelings,—the latter by the mere sight of the act in another person. The actions of Laughter and Crying seem never to originate in the respiratory system; but to be always either expressions of the emotions, or simple results of sensations,—as when crying arises from the sense of pain,—and laughter from that of tickling. The origin of the act of Hiccup does not seem very clear; but the movement is probably of a purely-reflex nature.

280. The purposes of the acts of Coughing and Sneezing are, in both instances, to expel substances from the air-passages, which are sources of irritation there; and this is accomplished in both, by a violent expiratory effort, which sends-forth a blast of air from the lungs.—*Coughing* occurs when the source of irritation is situated at the back of the mouth, in the glottis, trachea, or bronchial tubes. The irritation may be produced by acrid vapours, or by liquids or solids, that have found their way into these passages; or by secretions which have been poured into them in unusual quantity, as the result of disease; or by the simple entrance of air (especially if cold), when the membrane is in a peculiarly irritable state. Any of these causes may produce an impression upon the excitor fibres of the Pneumogastrics, which, being conveyed to the Medulla Oblongata, gives rise to the transmission of a motor impulse to the several muscles, that combines them in the act of coughing. This act consists,—1st, in a long inspiration, which fills the lungs; 2nd, in the closure of the glottis and of the larynx at its upper orifice by the approximation of the epiglottis to the walls of the pharynx (Ed. Smith), at the moment when expiration commences; and 3rd, in the bursting open (as it were) of the glottis, by the violence of the expiratory movement; so that a sudden blast of air is forced up the air-passages, carrying before it anything that may offer an obstruction.—The difference between Coughing and *Sneezing* consists in this,—that in the latter, the communication between the larynx and the mouth is partly or entirely closed by the drawing together of the sides of the velum palati over the back of the tongue; so that the blast of air is directed, more or less completely, through the nose, in such a way as to carry-off any source of irritation that may be present there.—It is difficult to say how far these actions are independent of consciousness, or how far they may require the stimulus of sensation for their performance.

281. Various alterations are produced in the Lungs by section of the Pneumogastric nerves; the inquiry into the nature and succession of which has been most carefully prosecuted by Dr. J. Reid;* and as his results have a very important bearing on several physiological and pathological questions of great interest, a summary of them will be here given.—In the first place, it has been fully established by Dr. Reid, that section of the Vagus on *one* side only does not necessarily, or even generally, induce disease of that lung; and hence the important inference may be drawn, that the nerve does not exercise any *immediate* influence

* Op. cit.

on its functions. When *both* Vagi are divided, however, the animal rarely survives long; but its death frequently results from the disorder of the digestive functions. Nevertheless, the power of digestion is sometimes restored sufficiently to re-invigorate the animals; and their lives may then be prolonged for a considerable time (§ 72). In fifteen out of seventeen animals experimented-on by Dr. Reid, the lungs were found more or less unfit for the healthy performance of their functions. The most common morbid changes were a congested state of the blood-vessels, and an effusion of frothy serum into the air-cells and bronchial tubes. In eight out of the fifteen, these changes were strongly marked. In some portions of the lungs, the quantity of blood was great as to render them dense. The degree of congestion varied in different parts of the same lung; but it was generally greatest at the most depending portions. The condensation was generally greater than could be accounted-for by the mere congestion of blood in the vessels, and probably arose from the escape of the solid parts of the blood into the tissue of the lung. In some instances the condensation was so great, that considerable portions of the lung sank in water, and did not crepitate; but they did not present the granulated appearance of the second stage of ordinary pneumonia. In five cases in which the animal had survived a considerable time, portions of the lungs exhibited the second, and even the third stages of pneumonia, with puriform effusion into the small bronchial tubes; and in two, gangrene had supervened.—One of the most important points to ascertain in an investigation of this kind, is the *first departure* from a healthy state; to decide whether the effusion of frothy reddish serum, by interfering with the usual change in the lungs, *causes* the congested state of the pulmonary vessels and the laboured respiration; or whether the effusion is the *effect* of a previously-congested state of the blood-vessels. The former is the opinion of many physiologists, who have represented the effusion of serum as a process of morbid secretion, directly resulting from the disorder of that function produced by the section of the nerve; the latter appears the unavoidable inference from the carefully-noted results of Dr. Reid's experiments. In several of these, only a very small quantity of frothy serum was found in the air-tubes, even when the lungs were found loaded with blood, and when the respiration before death was very laboured. This naturally leads us to doubt whether the frothy serum is the cause of the laboured respiration, and of the congested state of the pulmonary vessels, in those cases where it is present; though there can be no doubt that, when once it is effused, it must powerfully tend to increase the difficulty of respiration, and still further to impede the circulation through the lungs. Dr. R. has satisfied himself of an important point which has been overlooked by others, namely, that this frothy fluid is not mucus, though occasionally mixed with it, but that it is the frothy serum so frequently found in cases where the circulation through the lungs has been impeded before death. From this and other facts, Dr. R. concludes "that the congestion of the blood-vessels is the first departure from the healthy state of the lung, and that the effusion of frothy serum is a subsequent effect."*

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* For an interesting paper on this subject, the conclusions in which appear to be essentially confirmatory of the results obtained by Dr. Reid, see v. Boddart, "Journal de la Phys.," vol. v. 1862, pp. 442 and 527. This experimenter attributes all the

282. The next point, therefore, to be inquired-into, is the cause of this congestion; and this is most satisfactorily explained, in accordance with the general laws of the Circulation (§ 248), by remembering that section of the Pneumogastrics greatly diminishes the frequency of the respiratory movements, and that the quantity of air introduced into the lungs is, therefore, very insufficient for the due aeration of the blood. There is now abundant evidence, in regard to the Pulmonary circulation in particular, that to prevent the admission of oxygen in the lungs, either by causing the animal to breathe pure nitrogen or hydrogen, or by occlusion of the air-passages, is to bring the circulation through their capillaries to a speedy check. Hence we should at once be led to infer, that diminution in the number of Respiratory movements would produce the same effect; and as little or no difference in their frequency is produced by section of one Vagus only, the usual absence of morbid changes in the lung supplied by it is fully explained. The congestion of the vessels induced by insufficient aeration, satisfactorily accounts not only for the effusion of serum, but also for the tendency to pass into the inflammatory condition, sometimes presented by the lungs, as by other organs similarly affected. Dr. Reid confirms this view, by the particulars of cases of disease in the human subject, in which the lungs presented after death a condition similar to that observed in the lower animals after section of the Vagi; and in these individuals, the respiratory movements had been much less frequent than natural during the latter part of life, owing to a torpid condition of the nervous centres. The opinion (held especially by Dr. Wilson Philip) that section of the Par Vagum produces the serous effusion, by its direct influence on the function of Secretion, is further invalidated by the fact stated by Dr. Reid, that he always found the bronchial membrane covered with its true mucus, except when inflammation was present.—"The experimental history of the Par Vagum," it is justly remarked by Dr. Reid, "furnishes an excellent illustration of the numerous difficulties with which the physiologist has to contend, from the impossibility of insulating any individual organ from its mutual actions and reactions, when he wishes to examine the order and dependence of its phenomena." In such investigations, no useful inference can be drawn from one or two experiments only; in order to avoid all sources of fallacy, a large number must be made; the points in which all agree, must be separated from others in which there is a variation of results; and it must be then inquired, to what the latter is due.*

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effects of double section of the Pneumogastrics primarily to paralysis of the inferior laryngeal nerve on the one hand, and to paralysis of the pulmonary branches on the other; the former lesion permitting the entrance of foreign bodies into the bronchi, &c., and the latter lesion inducing *hyperæmia, emphysema,* and their consequences: whilst he considers paralysis of the œsophagus, together with modifications of the cardiac activity, and the occurrence of embolia in the divisions of the pulmonary artery, as secondary causes of the effects observed.

* On the important subject of the Mechanism of Respiration, the following Memoirs may be consulted in addition to those already referred-to:—Dr. J. Reid's Art. 'Respiration' in "Cyclop. of Anat. and Physiol.," vol. iv.; Dr. Hutchinson in "Med.-Chir. Trans.," vol. xxix.; Dr. Sibson in "Phil. Trans." 1846, "Med. Gaz.," vol. xli., "Med.-Chir. Trans.," vol. xxxi., and "Trans. of Prov. Med. Assoc.," 1850; Beau and Maissiat in "Archiv. Gén.," 1842; Mendelssohn, "Der Mechanismus der Respiration und Circulation," Berlin, 1845; and Vierordt, Art. 'Respiration' in "Wagner's Handwörterbuch der Physiologie," band ii.

2. *Effects of Respiration on the Air.*

283. The total amount of air which can be drawn into the Lungs by the deepest possible inspiratory movement, by no means affords a measure of the quantity which they ordinarily contain. It is in fact composed, as was first pointed-out by Mr. Julius Jeffreys,* of several different quantities, which may be distinguished as follows:—

1. *Residual Air;* that which cannot be displaced by the most powerful expiration, which always remains in the thorax so long as the lungs retain their natural structure, and over which, therefore, we have no control.

2. *Supplemental Air;* that portion which remains in the chest after the ordinary gentle expiration, but which may be displaced at will.

3. *Breathing* or *Tidal Air;* that volume which is displaced by the constant gentle inspiration and expiration.

4. *Complemental Air;* the quantity which can be inhaled by the deepest possible inspiration, over and above that which is introduced in ordinary breathing.

—The amount which can be expelled by the most forcible expiration after the fullest inspiration, and which is consequently the sum of the 2nd, 3rd, and 4th of these quantities, is designated by Dr. Hutchinson† as the *Vital Capacity*, being that volume of air which can be displaced by *living movements*. This 'vital capacity' is less dependent than might have been supposed, upon the absolute *dimensions* of the thoracic cavity, being yet more influenced by its *mobility*. Thus of two sets of men of the same height, one measuring 35 inches round the chest, and the other 38 inches, the average vital capacity of the first was found to be 235 inches, and that of the second only 226 inches; for notwithstanding the greater absolute capacity indicated by the larger circumference of the latter, the inferior mobility of the chest caused more 'residual air' to remain behind after the deepest expiration. By taking the average of nearly 5000 observations, Dr. Hutchinson has arrived at the very remarkable conclusion,‡ that of all the elements whose variation might be supposed to affect the 'vital capacity,' *Height* alone seems to have any constant relation to it; and that this relation is capable of being expressed in a simple numerical form. It may be briefly expressed by the rule, that *for every inch of stature, from five to six feet, eight additional cubic inches of air* (at 60° Fahr.) *are given-out by a forced expiration after a full inspiration:* the vital capacity for a man from 5 feet to 5 feet 1 inch, being 174 cub. in.; from 5 feet 1 inch to 5 feet 2 inches, 182 cub. in., and so on.—There is also a relation between 'vital capacity' and *Weight;* but of a different kind from that which might have been anticipated. So far as the increase in weight is simply proportional to the increase in height, the relation is of course the same for the one as for the other. But if the excess of weight should depend upon corpulence, the vital capacity *decreases* in a very marked manner, being always very low in corpulent men. The general result of Dr. Hutchinson's observations on this point, is expressed by him as follows: When the man exceeds the average weight (at each height) by 7 per cent, *the vital capacity decreases* 1 *cub. in. per lb. for the next* 35 *lbs. above this weight.*—The influence of *Age* upon the 'vital capacity' is less marked than might have been anticipated. The general fact seems to be, that the 'vital capacity' undergoes a slight increase between 15 and 35 years, and then gradually decreases, the decline being more rapid than the augmentation, so that by the age of 66 it has diminished to about 4-5ths of the maximum.—There does not seem to be as close a relation between the 'vital capacity' and *Muscular Vigour*, as might *à priori* have been expected, and as an attempt has been made to establish.[*] Cases are not unfrequent in which men of athletic constitution have an absolute deficiency, whilst others by no means remarkable for physical power present a large excess.[†] In fact, as Dr. C. R. Hall has justly remarked, this measure indicates, not what a person *does* breathe, but what he *can* breathe.—The *maximum* 'vital capacity' met-with by Dr. Hutchinson in his entire series of observations, was 464 cub. in.; this was in a man 7 feet high, whose weight was 308 lbs. The *minimum* was no more than 46 cub. in.; this was in a dwarf (Don Francisco), whose height was only 29 inches, and weight 40 lbs.

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* "Statics of the Human Chest," 1843.

† "Cyclop. of Anat. and Physiol.," vol. iv., Art. 'Thorax.'

‡ Op. cit., p. 1072.

284. But however constant the above averages may prove to be, when tested by a still larger number of observations, it yet remains to be determined within what limits individual variation may range, without departure from the standard of health. It is considered by Dr. Hutchinson[‡] that a deficiency of 16 per cent (unless the individual should be very corpulent) should excite suspicion of disease; but the observations of Dr. C. R. Hall (loc. cit.) seem to show that the range is considerably wider, especially in females. They also indicate that even a marked deficiency in vital capacity must not be regarded as indicative of pulmonary disease; for it may be dependent upon disorder of the abdominal viscera, especially upon congested liver.

285. In estimating, however, the effects of the Respiratory function upon the Air which passes through the lungs, we are not so much concerned with the quantity which *may* be drawn-in and forced-out, as with that actually exchanged at each movement. The estimates of the earlier observers, Herbst, Valentin,[§] &c., which ranged from 10 to 92 cub. in., are in general imperfect, having been based upon comparatively few respirations, and without taking into consideration the many circumstances we now know to exercise an influence upon the depth and frequency of the respiratory acts. Dr. Ed. Smith[‖] has arranged a spirometer, by which the quantity of air inspired may be registered from

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[*] See Dr. Jackson in "American Medical Examiner," 1851, p. 51.

[†] See Dr. C. Radclyffe Hall in "Trans. of Prov. Med. and Surg. Assoc.," 1851.

[‡] Op. cit., p. 1079.

[§] The following are some of the amounts assigned by different observers :—

Herbst		20—30 cubic inches.
Valentin		14—92
Vierordt		10—42
Coathupe		16
Hutchinson	average	16—20
	extreme	7—77

[‖] **Many of the following statements respecting Dr. Edward Smith's experiments have been kindly communicated by himself.**

1 to 100,000 cub. in., and therefore for any period. He has used it for 24 hours without intermission, except for meals, and ascertained the quantity of air inspired during sleep, and in almost every condition met with during the day. From numerous experiments upon several persons, each extending over a whole day, he found that the average depth of inspiration was 33·6 cub. in. when at rest, and when walking at 1, 2, 3, and 4 miles per hour, 52, 60, 75, and 91 cub. in., and even 107 cub. in. when working the treadmill. If we take 30 or 40 cubic inches as the average quantity exchanged at each respiration, we cannot but observe how small a proportion it bears to the entire amount which the lungs usually contain; for the 'residual air,' which cannot be expelled, is estimated by Dr. Hutchinson at from 75 to 100 cubic inches, and the 'supplemental air,' which can only be expelled by a forced expiration, is about as much more; the sum of the two being from 150 to 200 cub. in., or from 5 to 7 times the 'breathing volume.' Now it is obvious that if no provision existed for mingling the air inspired with the air already occupying the lungs, the former would penetrate no further than the larger air-passages; and as this would be again thrown-out at the next expiration, the bulk of the air contained in the lungs would remain altogether without renewal, and the expired air would not be found to have undergone any change.* That a change *is* effected, however, in the whole volume of the air contained in the lungs, with every inspiration, is indicated by the difference between the inspired and expired air; and this change must be attributed to the 'mutual diffusion' of gases, these tending to interpenetrate one another, when either of different densities or of different temperatures, according to the law discovered by Prof. Graham.

286. The *total amount* of Air which passes through the Lungs in twenty-four hours, will of course vary with the extent and frequency of the respiratory movements; and these are liable to be affected by many circumstances, but particularly by the relative degrees of repose and of exertion. Moreover, as any such computation must be based upon the datum of the ordinary volume of breathing or 'tidal' air, it is obvious that the estimates of different observers must vary with the amount they adopt. Dr. Ed. Smith found that during the day (6 A.M. to 12 night) the average quantity of air inspired by several persons at rest was 502 cub. in. per minute, or a total of 542,160 cub. in.; and as the average quantity during the night was about 400 cub. in. per minute, the total daily amount was 686,000 cub. in., which is in close approximation to the results of Valentin, who estimated the total daily amount at 688,348 cub. in. The quantity is largely increased by exertion, and Dr. Smith computes that the total amount actually respired by the unoccupied gentleman, the ordinary tradesman, and the hard working labourer, would be 804,780 cub. in., 1,065,840 cub. in., and 1,568,390 cub. in.; and with 12 hours of Alpine walking, as over the Wengern Alp, 1,764,000 cub. in. When carrying weights, as by the soldier in his heavy marching order, Dr. Smith found an increase of 7 cub. in. per minute for every 1 lb. weight carried.—It is of great practical importance to determine the

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* See Mr. Jeffreys' "Statics of the Human Chest," in which this important point first received due consideration.

quantity of air which ought to be allowed for consumption by individuals confined in prisons, workhouses, schools, &c.; and for this, experience seems to have fixed 800 cubic feet as the *minimum* that can be safely assigned, except where extraordinary provisions are in operation for its constant renewal by ventilation. The evil consequences of an insufficient supply of air will be noticed hereafter (Sect. 3).

287. The *alterations* in the Air[*] which are effected by Respiration, mainly consist in the removal of a portion of its *oxygen*, and the substitution of a quantity of *carbonic acid*, usually rather less in bulk than the oxygen which has disappeared. The proportion of the air thus changed, appears to vary according to the frequency of the respirations. Thus Vierordt[†] found that, if he only respired *six* times in a minute, the quantity of Carbonic acid was 5·5 per cent of the whole air exhaled; with *twelve* respirations, it was 4·2; with *twenty-four*, it was 3·3; with *forty-eight*, it was 3·0; and with *ninety-six*, it was 2·6 per cent. In some of the experiments of Messrs. Allen and Pepys, it was as much as 8 per cent. Probably about 4·35 per cent may be taken as the average amount of Carbonic acid added to the air, at the ordinary rate of respiration; whilst according to Vierordt, the amount of oxygen removed is 4·782 per cent; the absolute diminution in bulk of the expired air, when deprived of the moisture which it has acquired in passing through the lungs, being from 1-40th to 1-50th of its volume. It appears, however, that, if the air be already charged in some degree with Carbonic acid, the quantity exhaled is much less; for, when 300 cubic inches of air were respired for *three minutes*, only 28½ cubic inches (9½ per cent) of Carbonic acid were found in it; although the previous rate of its production, when fresh air was taken-in at every respiration, was 32 cubic inches in a minute (Allen and Pepys). Knowing, then, the necessity of a free excretion of Carbonic acid, we are led by this fact to perceive the high importance of ventilation; for it is not sufficient for health that a room should contain the quantity of air requisite for the support of its inhabitants during a given time; since after they have remained in it but a part of that time, the quantity of Carbonic acid which its atmosphere will contain, will be large enough to interfere greatly with the due aeration of their blood, and will thus cause oppression of the brain, and the other morbid affections that result from the accumulation of Carbonic acid in the circulating fluid.—It appears from the experiments of Dr. Snow, that the presence of Carbonic acid in the atmosphere acts more deleteriously upon the system, in proportion as the normal quantity of Oxygen has been reduced. He found that birds and mammalia, introduced into an atmosphere containing only from 10½ to 16 per cent of

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[*] The composition of ordinary atmospheric air in England is thus given by Dr. Miller ("Elements of Chemistry," vol. ii. p. 455):—

Oxygen	20·61	Nitric Acid, Ammonia, and Carburetted Hydrogen . . .	traces.
Nitrogen . . .	77·95		
Carbonic Acid . .	·04	And in towns — Sulphuretted Hydrogen and Sulphurous Acid	traces.
Aqueous vapour .	1·40		

The quantity of Aqueous Vapour is, however, liable to great variation; at the ordinary temperature of the month of July, the atmosphere is capable of containing nearly three times as much aqueous vapour as in December; nevertheless, the quantity of moisture actually present is generally greater in winter, owing to the greater rainfall.

[†] "Physiologie des Athmens," pp. 102–149.

oxygen, soon died, although means were taken to remove the carbonic acid set-free by their respiration, as fast as it was formed; whilst, on the other hand, an increase in the proportion of carbonic acid to 12 or even 20 per cent—the percentage of oxygen being kept to its regular standard of 21 per cent—did not appear to enfeeble the vital actions more rapidly, than did the reduction of the oxygen in the experiments just referred-to.* Hoppe† has observed that when rats were placed under the receiver of an air-pump, and exhaustion made till the pressure was reduced to 50 mm. (2 inches), fainting and convulsion were induced; and when it was reduced to 40 mm., death occurred apparently from the evolution of gas in the capillaries of the lungs, which impeded the passage of the blood. We may conjecture that the singular effects observed by Glaisher,‡ in his lofty balloon ascents, were due to the sudden and combined influence of cold and an insufficient supply of oxygen. The effects of increased atmospheric pressure on the respiration in Man have been observed by Vivenot;§ and an increase of one-fifth of the usual pressure is stated by him to decrease the respirations 2 per minute, and the number of pulsations on the average 10 per minute.

288. The absolute quantity of Carbonic acid exhaled from the Lungs is liable to variation from so many sources, that no fixed standard can be assigned for it. The mean of a great number of observations, however, made in different modes, and under different circumstances, would give about 160 grains of Carbon per hour as the amount set-free by a well-grown adult man, under ordinary circumstances. Taking this as the average of the twenty-four hours, the total quantity of Carbon thus daily expired from the Lungs would be 3840 grains, or 8 oz. Troy. According to Dr. Edward Smith, who has devised an apparatus by which the whole of the Carbonic acid exhaled may be collected for a whole day without intermission except for food, the total amount evolved in 24 hours at rest (deduced from experiments on different persons) was 7·144 oz. of Carbon; and he estimates that it should be increased to 8·68 oz. and 11·7 oz. for the non-labouring and laborious classes respectively, at their ordinary rate of exertion. The chief causes of variation are,—the Temperature and Hygrometric state of the surrounding Medium, Age, Sex, Development of the body, Nature and Quantity of Food and state of the Digestive Process, Muscular Exertion or Repose, Sleep or Watchfulness, Period of the Day, Season, and state of Health or Disease. These will now be considered in detail:—

I. *Temperature of surrounding Medium.*—The amount of Carbonic acid exhaled by warm-blooded animals, is greatly *increased* by external *Cold*, and *diminished* by *Heat*. From Letellier's‖ experiments it appears that the quantity of Carbonic acid exhaled by Mammals between 86° and

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* Bernard, however, found that a bird which lay exhausted from breathing in a limited quantity of air, recovered itself when the Carbonic acid was partially absorbed by caustic potash. He observed also that the circulation of blood charged with Carbonic acid rapidly stopped the activity of the secretory glands, as of the kidneys, which again recommenced as soon as oxygenated blood was allowed to pass through them. (Bernard, "Liq. de l'Organisme," 1859, vol. i. p. 505.

† "Müller's Archiv," 1857, p. 63.

‡ "Times," Sept. 1862.

§ Henle and Meissner, "Bericht," 1860, p. 322.

‖ "Annales de Chimie et de Physique," 1845; and M. Boussingault's "Mémoires de Chimie Agricole et de Physiologie," 1854.

106°, is less than *half* that set-free near the freezing-point; whilst that which is exhaled between 59° and 68° is but little more than *two-thirds* of the same amount. The diminution occasioned by heat is still more remarkable in Birds; which exhale at the highest temperature scarcely more than *one-third* of that set-free at the lowest.—The observations of Vierordt* upon himself show that the same is true of the Human subject; a difference of 10° Fahr., according to him, producing a variation of rather more than two cubic inches in the amount of Carbonic acid hourly expired. Dr. Ed. Smith found that sudden increase of temperature occasioned sudden decrease, in an increasing ratio, in the quantity of Carbonic acid evolved, amounting to 1·3 grain per minute for 16° Fahr. of temperature; but that in experiments continued over long periods, there was the greatest diversity in the proportion of Carbonic acid evolved to each degree of temperature.

II. That the *Hygrometric state of the Air* influences the rate of exhalation of Carbonic acid, appears from some experiments by Lehmann made with this express view. For he found that while 1000 grammes' weight of Pigeons yielded, in *dry* air, 6·055 grammes of Carbonic acid per hour, at the temperature of 75°, and 4·69 grammes at the temperature of 100°, the same animals, in *moist* air, yielded 6·769 grammes at 73°, and 7·76 grammes at 100°. And while 1000 grammes' weight of Rabbits exhaled, in *dry* air, 0·451 gramme per hour, at a temperature of 100°, they exhaled as much as 0·677 gramme in a *moist* atmosphere at the same temperature.†

III. *Age.*—The amount of Carbonic acid exhaled increases in both sexes up to about the thirtieth year; it remains stationary until about the forty-fifth; and it then diminishes. Thus, according to Andral and Gavarret,‡ at 8 years of age, 77 grains of carbon are excreted per hour; at 14 years, 126 grains; at 20 years, 166 grains; at 48 years, 162 grains; and at 76 years, 92·4 grains.

IV. *Sex.*—At all ages beyond eight years, the exhalation is greater in Males than in Females. Nearly the same proportionate increase takes place, however, in Females, up to the time of puberty; when the quantity abruptly ceases to increase, and remains stationary so long as they continue to menstruate. When, however, menstruation has ceased, the exhalation of Carbonic acid begins again to augment; and then again diminishes, with the advance of years, as in men. Should menstruation temporarily cease at any time, the exhalation of Carbonic acid immediately undergoes an increase, precisely as at the final cessation of the function. And during pregnancy, the exhalation increases in like manner.

V. *Development of the Body.*—The more robust the individual, *cæteris paribus*, the more Carbonic acid is exhaled; and the variation is much more influenced by the development of the muscular system, than by the height or weight, capacity of the chest, &c. Thus, a very strong man of twenty-six years of age exhaled at the rate of 217·1 grains of carbon per hour; while a man of moderate muscular power set-free but 169·4 grains in the same time. Another robust man of sixty years of age exhaled at the rate of 209·4 per hour; and an old man of ninety-two years, who still preserved an uncommon degree of energy, and who in his younger days had boasted of extraordinary muscular powers, exhaled at the rate of 135·5 grains per hour. So, also, a remarkably vigorous young woman of nineteen years exhaled at the rate of 107·8 grains per hour; and a strong woman of forty-four years (who had ceased to menstruate), 152·4 grains.—On the other hand, a slender man of forty-five years, in the enjoyment of good health, only exhaled at the rate of 132·4 grains per hour (Andral and Gavarret). In Dr. Ed. Smith's experiments the quantity of *carbon* expired per diem to each 1 lb. of body-weight was 17·07 grains, 17·51, and 17·99, at 48, 39, and 33 years of age respectively.

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* "Physiologie des Athmens," pp. 73-82.

† Lehmann, Op. cit., band iii. p. 304.

‡ "Annales de Chimie et de Physique," 1843.

VI. *Nature and Quantity of the Food, and State of the Digestive Process.*—It is well established, that the exhalation of Carbonic acid is greatly increased by eating, and that it is diminished by fasting. Thus Prof. Scharling states the hourly exhalation to have increased in one instance from 145 to 190, after breakfast and a walk; in another from 140 to 177, after breakfast alone; and in another from 111·9 to 188·9, after dinner. Dr. Ed. Smith on several occasions fasted for more than twenty-four hours, and collected all the Carbonic acid exhaled during the whole period, or during ten minutes at each hour of the waking day. He found the total daily amount of carbon exhaled at rest and whilst fasting to be 5·923 oz.; and there was scarcely any variation in the hourly quantity during the hours of the day. He noticed that there was a line below which the quantity of Carbonic acid did not fall, during waking hours in health; this, which he has termed the *basal line*, is that observed at rest and in the absence of food. The increase above that line, which is caused by food, seldom exceeds one-half of the basal quantity, or about 3 grains per minute. He has shown that the increase is from 2 to 3 grains per minute after breakfast and tea, and from 1 to 2 grains per minute after early dinner, whilst he scarcely found any increase after supper. He has examined the influence of numerous foods, as flesh, fish, albumen, gelatin, bread, rice, oatmeal, cane, grape, and milk sugar, milk, tea, coffee, cocoa, starch, gluten, butter, olive-oil, alcohol, rum, gin, brandy, sherry and port wine, beer and spirits. All nitrogenous foods—gluten, casein, flesh, fish, albumen, and gelatin—increased the evolution of Carbonic acid to the extent of ¾ to 1 grain per minute; but tea, coffee, bread, rice, oatmeal, milk, and sugar increased it from 1½ to 3 grains per minute. Fats and starch did not increase it; alcohol, rum, and ales increased it from ½ a grain to 2 grains per minute, whilst brandy and gin decreased it, and 3 ounces of wine exerted but little influence. The inhalation of the aroma of wines decreased it. All Dr. Smith's experiments were made in the sitting posture, at rest, before breakfast, and upon one substance alone in moderate quantity, the dose of which was repeated every ten or fifteen minutes, until the maximum influence had been obtained. With sugar, alcoholic liquids, tea, and coffee, the maximum influence was observed in from twenty to thirty minutes; but with bread, oatmeal, milk, and flesh, it was commonly later, and continued from 1½ to 2½ hours. With sugar and tea there was frequently an increase of 1 grain per minute in less than ten minutes. The whole of the Carbonic acid exhaled during five minutes at a time for two hours was collected and weighed: the percentage was not sought-for. Dr.

Smith has called attention to the separate action of the alcohol, aromas, sugars, and nitrogenous matters in each of the alcoholic compounds. Similar though less extended and perfect observations have been made by Vierordt, Bidder, Schmidt, and others, which generally corroborate the conclusions drawn by Dr. Ed. Smith.

VII. *Muscular Exertion or Repose.*—The effect of bodily exercise, in moderation, is to produce a considerable increase in the amount of Carbonic acid exhaled, both during its continuance, and for some little time subsequently to its cessation. According to the observations of Vierordt, the increase amounts to one-third of the quantity exhaled during rest, and it lasts for more than an hour afterwards; being manifested in the greater quantity of air respired, and in the larger percentage of Carbonic acid contained in it. If the exercise be prolonged, however, so as to occasion fatigue, it is succeeded by a diminished exhalation.—Dr. Ed. Smith found that whilst walking at two and three miles per hour, the quantity of Carbonic acid evolved was 18·1 grains and 25·83 grains per minute, which are respectively 1·85 and 2·64 times more than that eliminated in the quiet sitting posture. With treadwheel labour the quantity varied from 42·9 grains to 48·66 grains. After the exertion had ceased, the increase continued for some time; and not the least exertion could be made, even when sitting, without disturbing the results.—The connection between muscular exertion and the exhalation of Carbonic acid, is most remarkably shown in Insects; in which animals we may witness the rapid transition between the opposite conditions of extreme muscular exertion, and tranquil repose; and in which the effects of these upon the respiratory process are not masked by that exhalation of Carbonic acid, which is required in warm-blooded animals simply for the maintenance of a fixed temperature. Thus a Humble-Bee was found by Mr. Newport* to produce one-third of a cubic inch of Carbonic acid in the course of a single hour, during which its whole body was in a state of constant movement, from the excitement resulting from its capture; and yet, during the whole twenty-four hours of the succeeding day, which it passed in a state of comparative rest, the quantity of carbonic acid generated by it was absolutely less.

VIII. *Sleep or Watchfulness.*—The amount of Carbonic acid exhaled during sleep is considerably less than that set-free in the waking state. This is particularly shown by the experiments of Scharling;† who confined the subjects of them in an air-tight chamber, within which they could sleep, take their meals, &c. Thus in one case the hourly exhalation sank from 160 to 100, in another from 194·7 to 122·3, and in another from 99 to 75·1. Dr. Ed. Smith found that 4·88 and 4·99 grs. of Carbonic acid were exhaled per minute during light sleep from 1 to 3 A.M., and he estimates the quantity in profound sleep at 4½ grs. He also observed that 5·7 grs., 5·94 grs., and 6·1 grs. per minute were evolved at 1.30, 2.30, and 6.15 A.M., whilst awake, the average amount during the waking day being 9·77 grs. per minute in the same person. The cause of this result is partly to be sought in the cessation of all muscular exertion (save that concerned in the maintenance of the respiration); and partly in the diminution in the dissipation of the heat of the body itself.

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* "Philos. Transact.," 1836.

† "Ann. der Chem. und Pharm.," 1843; transl. in 'Ann. de Chim. et de Phys.,' 1843.

IX. *Period of the Day.*—Independently of these variations, which have their source in the condition of the individual, there is reason to believe that there is a diurnal cycle of change in the quantity of Carbonic acid exhaled; the *maximum* being (cæteris paribus) before and after noon, and the *minimum* before and after midnight. From the experiments of Scharling upon the Human subject, it would appear that the average proportion exhaled by day to that exhaled by night is as 1¼ to 1; and this difference does not seem to be affected by sleep or wakefulness. Dr. Ed. Smith found that the quantity of Carbonic acid varied at every moment; and that there were similar hourly variations in the quantity of Carbonic acid evolved, as in the rate of pulsations to which we have already referred. There was the least during the middle hours of the night, a slight increase with sunlight, a large increase after the meals, and a decrease before them, and a prolonged and inevitable fall after about 9 o'clock P.M. The proportion in the night of six hours to the day of 18 hours was in himself as 1 : 1·8. Most persons are conscious of a greater difficulty in bearing exposure to cold between midnight and early morning, than at any other period in the twenty-four hours.

X. *Season.*—Dr. Edward Smith has investigated the influence of season by determining the amount evolved at rest, in the sitting posture, and before breakfast, daily throughout the year, and has found that the greatest amount occurs in April and May; that there is a decrease commencing in June, and continuing progressively through June, July and August to September; and that in October, November, and December there is an increase. He considers that there is a maximum period (end of Winter and Spring), a minimum period (end of Summer to Autumn), an increasing period (Winter), and a decreasing period (early Summer). The extreme loss at the end of Summer was 3 grains of Carbonic acid per minute, or 33 per cent, and on the monthly average the loss was 17 or 18 per cent. He has applied this to the causation and treatment of disease, and has shown that the influence of the rotation of the seasons is a prime element in the *vis medicatrix naturæ*. Temperature and Barometric pressure to some extent, but very imperfectly, explained the results. A medium temperature was accompanied by the most diverse quantities of Carbonic acid at the different seasons; but extremes exhibited marked influence.

XI. *State of Health or Disease.*—Upon this very important cause of variation, few accurate researches have yet been made. The *percentage* of Carbonic acid in the expired air has been found to be unusually great in the Exanthemata, and in chronic Skin-diseases (Macgregor);* and it has been stated to be diminished in Typhus (Malcolm).†—Thus, the average proportion in health being about 4·3 per cent (Vierordt), it has been seen at 8 per cent in confluent Small-pox, at 5 per cent in Measles, and at 7·2 per cent in a severe case of Ichthyosis which terminated fatally; whilst in Typhus the percentage has been found to range from 1·18 to 2·50. But these statements do not indicate the total quantity exhaled in each case.—The remarkable increase of the exhalation in cases of

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* "Edinb. Monthly Journal," 1843. † "Report of Brit. Assoc.," 1843, p. 87.

Chlorosis has been already noticed; in four cases recorded by Hannover the hourly expiration was 123·6, 118·6, 116·9, and 106·3 grains; the absolute quantity diminishing as the respirations increased in rapidity.—In chronic diseases of the respiratory organs, as might be anticipated, the amount of Carbonic acid exhaled undergoes a sensible diminution (Nysten* and Hannover).†—Further researches are much needed on this subject; but, for obvious reasons, they cannot be readily made in severe forms of disease.

289. The aeration of the blood may take place, not only by means of the Lungs, but also in some degree through the medium of the Cutaneous surface. In some of the lower tribes of animals, indeed, this is a very important part of their respiratory process: and even in certain Vertebrata the cutaneous respiration is capable of supporting life for a considerable time. This is especially the case in the Batrachia, whose skin is soft, thin, and moist; and the effect is here the greater, since, from the small proportion of the blood that has passed through the lungs, that which circulates through the system is very imperfectly arterialized. By the experiments of Bischoff it was ascertained that, even after the lungs of a Frog had been removed, a quarter of a cubic inch of Carbonic acid was exhaled from the skin in the course of eight hours. Experiments on the Human subject leave no room for doubt, that a similar process is effected through the medium of his general surface, although in a very inferior degree; for by confining the body in a close chamber, into which the products of cutaneous respiration could freely pass, whilst the pulmonary respiration was measured by a distinct apparatus, Prof. Scharling‡ ascertained that the proportion of Carbonic acid given-off by the Skin is from 1-30th to 1-60th of that exhaled from the Lungs during the same period of time. Dr. Ed. Smith enclosed the whole of his body, except the head, in a Caoutchouc bag, passed a current of air through it, and collected the Carbonic acid. The whole quantity obtained in Summer, including that found in the air of the room, was 6 grains per hour, or somewhat more than 1 per cent of the amount passing off by the Lungs. Moreover, it has been observed, not unfrequently, that the livid tint of the skin which supervenes in Asphyxia, owing to the non-arterialization of the blood in the lungs, has given place after death to the fresh hue of health, owing to the reddening of the blood in the cutaneous capillaries by the action of the atmosphere upon them; and it does not seem improbable that, in cases of obstruction to the due action of the lungs, the exhalation of Carbonic acid through the skin may undergo a considerable increase; for we find a similar disposition to vicarious action in other parts of the excreting apparatus. There is also evidence that the interchange of gases between the air and the blood, through the Skin, has an important share in keeping-up the temperature of the body (CHAP. X.); and we find the temperature of the surface much elevated in many cases of pneumonia, phthisis, &c., in which the lungs seem to perform their function very insufficiently.

290. The total amount of Carbonic acid daily given-off from the Skin

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* "Recherches de Physiologie et de Chimie Pathologiques," 1811.

† "De Quantitate relativa et absoluta Acidi Carbonici ab Hominc Sano et Ægroto exhalati," 1845.

‡ "Ann. der Chem. und Pharm.," 1846.

and Lungs may be estimated in another mode; namely, by determining the total amount of Carbon contained in the *ingesta*, and the amount excreted in other ways, making allowance for the difference in weight (if any) of the body. In this mode, Prof. Liebig came to the conclusion, that the average amount of carbon exhaled by soldiers in barracks was 13·9 oz. (Hessian) or very nearly 14 oz. troy. From similar collective observations upon the inmates of the Bridewell at Marienschloss (a prison where labour is enforced), he calculated that each individual exhaled 10·5 oz. of carbon daily in the form of Carbonic acid; while in a prison at Giessen, whose inmates are deprived of all exercise, the daily average was but 8·5 oz.[*] It has been shown by Prof. Scharling,[†] that the total amount of carbon contained in the daily allowance of food and drink in the Danish Navy is somewhat less than 10·5 oz.; and as we shall presently see that from 1-10th to 1-12th of the carbon ingested passes-off through other channels, scarcely more than 9·5 oz. of this amount can be consumed by the respiratory process.—A very exact estimate, though based on more limited data, was made by M. Barral;[‡] who experimented upon himself (æt. 29) in winter (A) and in summer (B), upon a boy 6 years old (C), upon a man 59 years old (D), and upon an unmarried woman of 32 years (E). The following table gives the results which he obtained, from an average of five days, in regard to the disposal of the Carbon of the food; those which relate to its Nitrogen, Hydrogen, and Oxygen will be noticed subsequently (§§ 292, 293).

	Weight of Body.	*Carbon of Food.*	*Carbon excreted.*		
			In Fæces.	In Urine.	By exhalation.
A	104·5 lbs.	5654·1 grs.	236·2 grs.	234·6 grs.	5183·3 grs.
B	——	4090·0 ,,	137·4 ,,	211·5 ,,	3741·1 ,,
C	33 ,,	2382·3 ,,	149·7 ,,	67·9 ,,	2164·7 ,,
D	129·1 ,,	5123·0 ,,	210·0 ,,	327·3 ,,	4585·7 ,,
E	134·6 ,,	4520·8 ,,	64·8 ,,	216·1 ,,	4239·9 ,,

Thus the average amount of the Carbon daily consumed in pulmonary and cutaneous exhalation by M. Barral himself, was in winter 5183·3 grains, or 10·8 oz. troy; whilst in summer it was but 3741·1 grains, or 7·8 oz. troy; this difference is quite conformable to what might have been anticipated from the results of a different mode of experimenting (§ 288, I.); and it throws some light on the discrepancies in the results of other measurements, to find that the seasonal variation is scarcely less than one-third of the mean between these two amounts. The other results correspond closely with the statements of MM. Andral and Gavarret, in regard to the higher proportion of Carbonic acid exhaled (as compared with the bulk of the body) by children, and the smaller proportion thrown-off by men advanced in years, and by women. In some experiments made on himself in Pettenkofer's apparatus, Ranke (weighing 161 lbs.) found that when at rest and fasting, 10,190 grains of Carbonic acid or 2779 grains of Carbon were eliminated in twenty hours by the Skin and Lungs, whilst with as full a diet as possible the amount was 13,278 grains of Carbonic acid, or 3621 grains of Carbon.

291. It is not only by an oxygenated atmosphere that the removal of

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[*] Op. cit., p. 46.

[†] "Ann. der Chem. und Pharm.," 1846.

[‡] "Ann. de Chim. et de Phys.," tom. xxv.

Carbonic acid from the blood may be effected. For although it was formerly supposed that the exhaled Carbonic acid is generated in the lungs by the combination of atmospheric oxygen with the carbonaceous matters of the blood, and that the inhalation of oxygen is therefore immediately necessary for its production, yet it is now quite certain that this Carbonic acid exists preformed in venous blood, and that the oxygen introduced is carried into the arterial circulation, instead of being at once returned to the air in the state of Carbonic acid (§ 169). Hence an exhalation of Carbonic acid may continue for a considerable period (in cold-blooded animals especially), whilst the animal is breathing an atmosphere in which no oxygen exists. Thus it was shown by Spallanzani,* that snails might be kept for a long time in Hydrogen, without apparent injury to them; and that during this period they disengaged a considerable amount of Carbonic acid. Dr. Edwards† subsequently ascertained that, when Frogs were kept in hydrogen for several hours, the quantity of Carbonic acid exhaled was fully as great as it would have been in atmospheric air, or even greater; this latter fact, if correct, may be accounted-for by the superior displacing power which (on the laws of the diffusion of gases) hydrogen possesses for Carbonic acid. Collard de Martigny‡ repeated this experiment in Nitrogen, with the same results. In both sets of experiments, the precaution was used of compressing the flanks of the animal, previously to immersing it in the gas, so as to expel from the lungs whatever mixture of oxygen they might contain. These experiments have been since repeated by Muller and Bergemann, who took the additional precaution of removing, by means of the air-pump, all the atmospheric air that the lungs of the frog might previously contain, together with the Carbonic acid that might exist in the alimentary canal. They found in one of their experiments, that the quantity of Carbonic acid exhaled in hydrogen was nearly a cubic inch in 6½ hours; and in another, that nearly the same amount was given-off in nitrogen, though this required rather a longer period. It appears from the table of their results,§ that the amount was not ordinarily greater in the experiments which were prolonged for twelve or fourteen hours, than in those which were terminated in half the time; hence it may be inferred, that the quantity which the blood is itself capable of disengaging is limited, and that the absorption of oxygen is necessary to enable Carbonic acid to be continuously set-free from the body.—It is impossible, however, for an *adult* Bird or Mammal to sustain life for any considerable time in an atmosphere deprived of oxygen; since the greatly-increased rapidity and energy of all their vital operations necessitate a much more constant supply of this vivifying agent, than is needed by the inferior tribes; and, as we shall presently see, the capillary action requisite for the passage of the blood through the lungs will not take place without it (§ 299). But Dr. Edwards has shown that *young* Mammalia can sustain life in an atmosphere of hydrogen or nitrogen, for a sufficient length of time to exhale a sensible amount of Carbonic acid; so that the character of the process is clearly proved to be the same in warm-blooded animals as in Reptiles and Invertebrata.

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* "Mémoires sur la Respiration," traduit par Senebier, Genève, 1804.

† "De l'Influence des Agens Physiques sur la Vie," Paris, 1824.

‡ 'Recherches Expérimentales,' &c. in Magendie's "Journal de Physiologie," tom. x.

§ Muller's "Elements of Physiology," translated by Baly, vol. i. p. 338.

292. Much discussion has taken place with regard to the degree in which the proportion of *Nitrogen* in the air is affected by Respiration. It seems probable that the absorption and exhalation of this gas are continually taking place; but that the two amounts usually nearly balance each other.* On the whole, however, there is adequate reason to believe that Nitrogen is ordinarily given-off; this being the joint result of the analysis of the expired air, and of the comparison of the amount of nitrogen given-off in the other excretions with that ingested as a constituent of the food. In some experiments made by Regnault and Reiset, on the composition of the expired air in various warm-blooded animals, they arrived at the following conclusions:—(1). That warm-blooded animals subjected to their ordinary regimen exhale nitrogen, but never in larger proportion than 1-50th, and sometimes in less than 1-100th, of the oxygen consumed;—(2). That in a state of inanition, animals usually absorb nitrogen;—(3). That animals whose usual diet has been changed, usually absorb oxygen until they are accustomed to their new food.†—In other experiments made by Boussingault upon turtle-doves, and by Barral upon the Human subject, in which a comparison was made between the amount of Nitrogen given-off in the other excretions, and that ingested as a constituent of the food, it was determined that the surplus of nitrogen in the food of the birds above that excreted by the kidneys and intestinal canal was 2¼ grains daily, or one-third of the weight of the nitrogen in their food; whilst Barral estimated that the amount of nitrogen which (being otherwise unaccounted for) must be considered to have passed-off by the lungs and skin, varied from 1-75th (in an adult) to 1-143rd (in a child) of the oxygen consumed, the former proportion agreeing very well with that deduced by MM. Regnault and Reiset from their experiments on animals. —It will be remembered that Nitrogen exists in an uncombined state in the blood (§ 169); its percentage, however, is continually varying; and no constant difference is observable between the proportions yielded by arterial and venous blood respectively.

[The alterations effected in the *Blood* by Respiration have already been fully considered. See §§ 168-170.]

293. *Exhalation and Absorption through the Lungs.*—The Air expired from the lungs differs from that which was introduced into them, not merely in the altered proportions of its Oxygen, Nitrogen, and Carbonic acid, but also in having received (under ordinary circumstances at least) a large addition to its watery vapour. This it doubtless acquires in accordance with physical laws, through its exposure to the warm blood which is spread-out over a very extensive surface, the intermediate membrane being extremely permeable; and the variations in its amount will depend upon the physical conditions under which that exposure takes place. The air expired in ordinary respiration is charged with as much watery vapour as saturates it at the temperature of the body; and consequently the amount of watery vapour thus exhaled will vary (for equal volumes of air at any given temperature) in the inverse proportion

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* For the considerations which render this probable, see especially Dr. W. F. Edwards "On the Influence of Physical Agents on Life," part iv., chap. xvi., sect. 2, 3.

† "Ann. de Chim. et de Phys.," 1849; and "Mém. de Chim. Agric.," 1854, p. 31.

to that which the air previously contained. But when the air is very cold and very dry, and the respiration is unusually rapid, it may not remain sufficiently long in the air-cells to be raised to the temperature of the body, or to be fully saturated with moisture. The amount of watery vapour exhaled, moreover, will of course depend in part upon the quantity of air which passes through the lungs. And from these causes of difference, it happens that the amount of watery vapour exhaled in twenty-four hours may vary from about 6 oz. to 27 oz.; its usual range, however, being between 7 and 11 oz. Dr. Ed. Smith found that during a long fast the quantity of vapour exhaled by the lungs was 2·02 grs. per minute, or ·548 gr. in every 100 cub. in. of expired air. With food and at rest, the quantity varied from 3 grs. to 3·4 grs. per minute. The inhalation of alcoholic vapours increased the quantity of vapour exhaled; when alcohol was drunk the quantity was also increased, but it was decreased under the action of gin.—Of the fluid ordinarily exhaled with the breath, a part doubtless proceeds from the moist lining of the nostrils, fauces, &c.; but it is indisputable that the greater proportion of it comes from the lungs, since, when the respiration is entirely performed through a canula introduced into the trachea, the amount of watery vapour which the breath contains is still very considerable. Of the proper pulmonary exhalation, there can be no doubt that the greater part is the mere surplus-water of the blood, and especially of the crude fluid which has been newly introduced into the circulating current by the process of nutritive absorption. But there is strong evidence that Hydrogen as well as carbon undergoes combustion in the system, and that a portion of the exhaled aqueous vapour is the product of that combustion. For of the hydrogen which the food contains, not more than from 1-8th to 1-10th passes-off by the other excretions, the remaining 7-8ths or 9-10ths being exhaled in the condition of watery vapour from the lungs. A portion of the oxygen which this vapour contains is supplied by the food; but there is usually a considerable surplus of hydrogen, and this can only be converted into water at the expense of oxygen derived from the atmosphere. Upon this point the experiments of M. Barral (loc. cit.) gave the following results:—that, of the Hydrogen exhaled from his lungs and skin, in the condition of watery vapour, not less than 321·1 grs. in winter, and 252·8 grs. in summer, must have been converted into water by oxygen derived from the air; and this calculation would give 2889·9 grs. (6 oz. troy) for the winter, and 2275·2 grs. (4·7 oz. troy) for the summer, as the amount of water thus generated in the combustive process. This, however, can only be regarded as an approximation to the truth; since there are many circumstances not taken into account in the computation, by which the estimate may be affected.

294. The fluid thrown-off from the lungs is not pure Water. It holds in solution, as might have been expected, a considerable amount of Carbonic acid, and also some animal matter, which, from the inquiries of Dr. R. A. Smith,* would appear to be an albuminous substance in a state of decomposition. According to Wiederhold,† the Chlorides of Sodium and Ammonium, Uric Acid and the Urates of Soda and Ammonia, may be detected in the expired air. If the fluid be kept in a closed vessel, and

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* "Philosophical Magazine," vol. xxx. p. 478. † "Deutsche Klinik," 1858.

be exposed to an elevated temperature, a very evident putrid odour is exhaled by it. Every one knows that the breath itself has, occasionally in some persons, and constantly in others, a fœtid taint: when this does not proceed from carious teeth, ulcerations in the air-passages, disease in the lungs, or other similar causes, it must result from the excretion of the odorous matter, in combination with watery vapour, from the pulmonary surface. That this is the true account of it, seems evident from the analogous phenomenon of the excretion of turpentine, camphor, alcohol, and other odorous substances, which have been introduced into the venous system, either by natural absorption, or by direct injection; and also from the suddenness with which it often manifests itself, when the digestive apparatus is slightly disordered, apparently in consequence of the entrance of some mal-assimilated matter into the blood. Among the substances occasionally thrown-off by the lungs, Phosphorus deserves a special mention, on account of the peculiarity of the form under which it is eliminated; for it has been found that if phosphorus be mixed with oil, and be injected into the blood-vessels, it partly escapes in an unoxidized state from the lungs, rendering the breath luminous.* And this luminous breath has also been observed in spirit-drinkers; in whom the oxidation of the effete matters of the system is impeded, in consequence of the demand set-up by the alcohol ingested for the oxygen introduced (§ 288, VIII.).

295. Not only exhalation, but also (under peculiar circumstances) *absorption* of fluid may take place through the Lungs. Thus Dr. Madden† has shown that, if the vapour of hot water be inhaled for some time together, the total loss by exhalation is so much less than usual, as to indicate that the cutaneous transpiration is partly counterbalanced by pulmonary absorption; the pulmonary exhalation being at the same time entirely checked. It is probable that, if the quantity of fluid in the blood had been previously diminished by excessive sweating, or by other copious fluid secretions, the pulmonary absorption would have been much greater. Still in the cases formerly mentioned (§ 118), in which a large increase in weight could only be accounted-for on the supposition of absorption of water from the atmosphere, it seems probable that the cutaneous surface was chiefly concerned; for it can only be when the air introduced into the lungs is *saturated* with watery vapour, that the usual exhalation will be checked, or that any absorption can take place.

296. That absorption of other volatile matters diffused through the air, however, is continually taking place by the Lungs, is easily demonstrated. A familiar example is the effect of the inhalation of the vapour of Turpentine upon the urinary excretion. It can only be in this manner that those gases act upon the system, which have a noxious or poisonous effect when mingled in small quantities in the atmosphere; and it is most astonishing to witness the extraordinary increase in potency which many substances exhibit, when they are brought into relation with the blood in the gaseous form. The most remarkable example of this kind is afforded by Arseniuretted Hydrogen, the inspiration of a few hundredths of a grain of which has been productive of fatal consequences, the resulting symptoms being those of arsenical poisoning. Next to this,

* "Casper's Wochenschrift," 1849, band xv.

† "Prize Essay on Cutaneous Absórption," p. 55.

perhaps, in deleterious activity, is Sulphuretted Hydrogen; but it would seem that the effects of this gas upon the Human subject are scarcely so violent as they are upon animals; for though it has been found that the presence of 1-500th part of it in the respired air will destroy a bird in a very short time, that 1-800th part suffices to kill a dog, and that 1-250th part is fatal to a horse, yet M. Parent-Duchâtelet has affirmed that workmen habitually breathe with impunity an atmosphere containing *one per cent*, and that he himself has respired, without serious symptoms ensuing, air which contained *three per cent.* There can be no doubt, however, that the *continued* inhalation of air thus contaminated would be speedily fatal. Sulphuretted hydrogen and Hydro-sulphuret of ammonia are given off from most forms of decaying animal and vegetable matter; and it is undoubtedly to the accumulation of these gases, that the fatal results which sometimes ensue from entering sewers are to be chiefly attributed.—Carburetted hydrogen is another gas whose effects are similar; but a larger proportion of it is required to destroy life.—Carbonic acid gas, also, appears to be absorbed by the lungs, when a large proportion of it is contained in the atmosphere. The accumulation of this gas in the blood, when the respired air is charged with it even to a moderate amount, might be attributed to the impediment thus offered to its ordinary exhalation (§ 286); but the following experiment appears to prove that it may be actually absorbed into the blood, and that it will thus exert a really-poisonous influence, not merely produce an asphyxiating effect. It was found by Rolando, that the air-tube of one lung of the land-tortoise may be tied, without apparently doing any material injury to the animal, as the respiration performed by the other is sufficient to maintain life for some time; but, having contrived to make a tortoise inhale carbonic acid by one lung, whilst it breathed air by the other, he found that the animal died in a few hours.*—Cyanogen is another gas which has an actively-poisonous influence upon animals, when absorbed into the lungs; its agency, also, is of a narcotic character.

297. It is singular that the effects of the respiration of pure Oxygen should not be dissimilar. At first the rapidity of the pulse and the number of the respirations are increased, and the animal appears to suffer little or no inconvenience for an hour; but symptoms of coma then gradually develope themselves, and death ensues in six, ten, or twelve hours. If the animals be removed into the air before the insensibility is complete, they quickly recover. When the body is examined, the heart is seen beating strongly, while the diaphragm is motionless; the whole blood in the veins, as well as in the arteries, is of a bright scarlet colour; and several of the membranous surfaces have the same tint. The blood is observed to coagulate with remarkable rapidity; and it is to the alteration in its properties occasioned by hyper-arterialization (§ 170), and indicated by this condition, that we are probably to attribute the

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* The fatal result of breathing the fumes of charcoal is, therefore, not simple Asphyxia, such as would result from breathing hydrogen or nitrogen.—Other volatile products are set-free in the combustion of charcoal, besides carbonic acid. Mr. Coathupe (loc. cit.) states these to be Carbonate, Muriate, and Sulphate of Ammonia, Carbonic Oxide, Oxygen, Nitrogen, Watery vapour, and Empyreumatic Oil: to these, Sulphurous acid may appear to be properly added.

fatal result. There can be no doubt that, in this instance, an undue amount of oxygen is absorbed; and it does not seem unlikely that whilst one cause of the fatal result is a stagnation of the blood in the systemic capillaries, consequent upon the want of sufficient change in its passage through them (§ 248), another, and perhaps still more important one, is to be found in the diminished activity of the respiratory nervous centres, consequent upon the presence in their capillaries of blood surcharged with oxygen (§ 272). When Nitrogen or Hydrogen is breathed for any length of time, death results from the deprivation of Oxygen, rather than from any deleterious influence which these gases themselves exert.—Death is also caused by the inhalation of several gases of an irritant character, such as Sulphurous, Nitrous, and Muriatic acids; but it is doubtful how far they are absorbed, or how far their injurious effects are due to the abnormal action which they excite in the lining membrane of the air-cells and tubes.—It cannot be doubted that Miasmata and other morbific agents diffused through the atmosphere, are more readily introduced into the system through the pulmonary surface than by any other; and our aim should therefore be directed to the discovery of some counteracting agents, which can be introduced in the same manner. The Pulmonary surface affords a most advantageous channel for the introduction of certain medicines that can be raised in vapour, when it is desired to affect the system with them speedily and powerfully; such is pre-eminently the case with those Anæsthetic agents, ether and chloroform, whose introduction into the various departments of Medical and Surgical practice constitutes a most important era in the history of the healing art; also with Mercury,* Iodine, Tobacco, Stramonium, &c.

3. *Effects of Suspension or Deficiency of Respiration.*

298. We have now to consider the results of the cessation of the Respiratory function, and the consequent retention of Carbonic acid in the blood. If this be sufficiently prolonged, a condition ensues to which the name of *Asphyxia* has been given; the essential character of which is the cessation of muscular movement, and shortly afterwards of the Circulation; with an accumulation of blood in the venous system. The time which is necessary for life to be destroyed by Asphyxia varies much, not only in different animals, but in different states of the same. Thus, warm-blooded animals are much sooner asphyxiated than Reptiles or Invertebrata; on the other hand, a hybernating Mammal supports life for many months, with a respiration sufficiently low to produce speedy asphyxia if it were in a state of activity. And among Mammalia and Birds, there are many species which are adapted, by peculiarities of conformation, to sustain a deprivation of air for much more than the average period.† Excluding these, it may be stated as a general fact, that, if a

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* The beneficial results of the introduction of Mercury by inhalation, are strikingly set forth in Mr. Langston Parker's Essay on "The Treatment of Secondary, Constitutional, and Confirmed Syphilis."

† Thus, the Cetacea contain far more blood in their vessels, than do any other Mammalia; and these vessels are so arranged, that both arteries and veins are in connection with large reservoirs or diverticula. The reservoirs belonging to the former are usually full; but when the Whale remains long under water, the blood which they contain is gradually introduced into the circulation, and, after becoming venous, accumulates in the reservoirs connected with the venous system. By means of this provision, the Whale can remain under water for more than an hour.

warm-blooded animal in a state of activity be deprived of respiratory power, its muscular movements (with the exception of the contraction of the heart) will cease within five minutes, often within three; and that the circulation generally fails within ten minutes. Thus, in the experiments made by the Committee of the Royal Medico-Chirurgical Society,* it was found that when death by drowning took place rapidly, it was due to the entrance of Water into the lungs; and that if the entrance of Air into the lungs was prevented by suddenly inserting a cork into a glass tube tightly tied into the trachea, the average duration of the efforts to inspire was 4 minutes 5 seconds in dogs, and 3 minutes 25 seconds in rabbits; whilst the average duration of the heart's action was 7 minutes 11 seconds in dogs, and 7 minutes 10 seconds in rabbits. It was found also that in simple Apnœa recovery might take place after deprivation of air for 3 minutes 50 seconds, whilst immersion for 1½ min. was usually fatal.—Brown-Séquard† has shown by numerous experiments, that both newly-born animals and adults are capable of resisting the Asphyxia which results from submersion, by so much longer a period as their temperature is lower, providing it does not descend below 64° F. As a general rule, the newly-born animal can survive submersion for a longer period than the adult; this, however, does not hold in the case of guinea-pigs. Of 14 newly-born rabbits submersed in water at 77° F., 5 had a temperature of 95° to 96½° F., and survived, on the average, 12½ minutes: 4 had a temperature of 82° to 89° F., and survived 17 minutes: lastly, 5 had a temperature of from 64° to 70° F., and these survived, on an average, 26½ minutes. A newly-born dog will survive, if its temperature be low, an immersion of 50 minutes' duration.—Many persons are capable of sustaining a deprivation of air for two, three, or even four minutes,‡ without insensibility or any other injury; but this power, which seems possessed to the greatest degree by the divers of Ceylon, can only be acquired by habit. The period during which remedial means may be successful in restoring the activity of the vital and animal functions, is not, however, restricted to this. There is one well-authenticated case, in which recovery took place after a continuous submersion of fifteen minutes:§ and

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[*] "Trans.," vol. xlv. p. 449.

[†] "Journal de la Phys.," vol. ii. p. 98 *et seq.*

[‡] Dr. Hutchinson states that any man of ordinary 'vital capacity' can pass two minutes without breathing, if he first makes five or six forcible inspirations and expirations, so as to cleanse the lungs of the old air, and then fills his chest as completely as he can. "For the first 15 seconds, a giddiness will be experienced; but when this leaves us, we do not feel the slightest inconvenience for want of air." (See "Cyclop. of Anat. and Phys.," vol. iv. p. 1066.)

[§] The following are the facts of this case, as narrated by Marc ("Manuel d'Autopsie Cadavérique Médico-Légale," p. 165) on the authority of Prater:—A woman convicted of infanticide was condemned to die by drowning. This punishment was formerly inflicted in Germany according to the now obsolete Caroline law, the culprit being inclosed in a sack with a cock and a cat, and sunk to the bottom of the water. In this instance, the woman, after having been submerged for a quarter of an hour, was drawn-up, and *spontaneously* recovered her senses. She stated that she had become insensible at the moment of her submersion; a circumstance which adds considerable weight to the supposition, based upon the post-mortem appearances in many cases of drowning, that death often takes place as much by Syncope (or primary failure of the heart's action, consequent upon sudden and violent emotion, or upon physical shock) as by Asphyxia. If the reality of this state of Syncopal Asphyxia be admitted, there does not seem any adequate reason for limiting the possible persistence of vitality in a submerged body, even to half an hour; especially if the temperature of the water be such as not to cause any rapid abstraction of its heat.

many others are on record, of the revival of drowned persons after an interval of half an hour, or even more; but there is not the same certainty in regard to these, that the individuals may not have occasionally risen to the surface and taken breath there. It is not improbable, however, that in some of these cases a state of Syncope had come-on at the moment of immersion, through the influence of fear or other mental emotion, concussion of the brain, &c.; so that, when the circulation was thus enfeebled, the deprivation of air would not have the same injurious effect, as when this function was in full activity. The case would then closely resemble that of a hybernating animal; for in both instances the being might be said to live very slowly, and would therefore not require the usual amount of respiration. The condition of the still-born infant is in some respects the same; and re-animation has been successfully attempted, when nearly half an hour had intervened between birth and the employment of resuscitating means, and when probably a much longer time had elapsed from the period of the suspension of the circulation.

299. It has now been sufficiently proved, both by experiment and by pathological observation, that the first effect of the non-arterialization of the blood in the lungs is the retardation of the fluid in their capillaries, and also in those of the system generally; consequently, the arterial system becomes gorged with blood, the beats of the heart are frequent and energetic, its left side is distended, and a manometer introduced into the arterial system shows for a short time an increase in the pressure. The same condition holds with the right side of the heart and the pulmonary artery. The blood passes with difficulty through the capillaries of the lungs, and the venous system becomes turgid with blood. Then the arterial system begins slowly to empty itself of its blood, partly by contraction of its muscular tissue, stimulated by the presence of imperfectly-aerated blood, and partly by its natural elasticity, and thus a still greater accumulation takes place in the venous system. It is some time, however, before a complete stagnation takes place, since, as long as the proportion of oxygen which remains in the air in the lungs is considerable, and that of the carbonic acid is small, so long will some imperfectly-arterialized blood find its way back to the heart, and be transmitted to the system. This blood exerts a depressing influence upon the nervous centres, which is aided by the diminution that gradually takes place in the quantity of blood propelled to them; and thus the powers of the Sensorial centres are suspended, so that the individual becomes unconscious of external impressions; whilst the activity of the Medulla Oblongata also becomes diminished, so that the respiratory movements are enfeebled. The progressive exhaustion of the oxygen of the air in the lungs, and the accumulation of carbonic acid in the blood,* increase the obstruction in the pulmonary capillaries; less and less blood is delivered to the systemic arteries, and what is thus transmitted becomes more and more venous; the nervous centres are now completely paralyzed, and the respiratory movements cease; and the deficient supply of blood, with the

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* Setschenow has made some important researches on the amount and kind of gases contained in the blood of asphyxiated animals (dogs). He found that only traces of oxygen could be discovered in either the venous or arterial blood: the quantity of nitrogen varied from 1 to 2 parts, of free carbonic acid from 28 to 38·8 parts, and of combined carbonic acid from 1·7 to 4 parts. (Henle and Meissner, "Bericht," 1859, p. 305).

depravation of its quality, act injuriously upon the muscular system also, and especially weaken the contractility of the heart. In this enfeebled state, the final cessation of its movements seems attributable to two distinct causes, acting on the two sides respectively; for on the right side it is the result of the over-distension of the walls of the ventricle, owing to the accumulation of venous blood; and on the left to deficiency of the stimulus necessary to excite the movement, which is no longer sustained by its spontaneous motility. The heart's contractility is not finally lost, however, nearly as soon as its movements cease; for the action of the right ventricle may be renewed, for some time after it has stopped, by withdrawing a portion of its contents—either through the pulmonary artery, their natural channel—or, more directly, by an opening made in its own parietes, in the auricle, or in the jugular vein (§ 219). On the other hand, the left ventricle may be again set in action, by renewing its appropriate stimulus of arterial blood. Hence, if the stoppage of the circulation have not been of too long continuance, it may be renewed by artificial respiration;* for the replacement of the carbonic acid by oxygen in the air-cells of the lungs, restores the circulation through the pulmonary capillaries; and thus at the same time relieves the distension of the right ventricle, and conveys to the left the due stimulus to its actions.—Of the mode in which the Pulmonary circulation is thus stagnated by the want of oxygen, and renewed by its ingress into the lungs, no other consistent explanation can be given, than that which is based on the doctrine already laid-down in regard to the capillary circulation in general (§ 248); namely, that the performance of the normal reaction between the blood and the surrounding medium (whether this be air, water, or solid organized tissue) is a condition necessary to the regular movement of the blood through the extreme vessels. That no mechanical impediment to its passage is created (as some have maintained) by the want of distension of the lungs, has been fully proved by the experiments of Dr. J. Reid on the induction of Asphyxia by the respiration of Nitrogen. And that a contraction of the small arteries and capillaries, under the stimulus of venous blood, cannot be legitimately assigned as the cause of the obstruction, is evident from the consideration brought to bear upon it by the same excellent experimenter; namely, the *suddenness* with which the flow is renewed on the admission of oxygen, as contrasted with the *slowness* with which arteries dilate after the removal of the cause of their contraction (§ 226).†

300. It is obvious that by the repeated passage of the same air through the lungs, it must, though originally pure and wholesome, become so strongly impregnated with Carbonic acid, and must lose

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* Of the two chief modes of performing this operation, Dr. Sylvester's method of alternately raising and depressing the arms, appears to be far preferable to Dr. Marshall Hall's method of rotating the body half over, and pressing on its chest. See Marshall Hall's work on "Drowning," and "Med. Times and Gaz.," 1858, vol. i. pp. 147, 176 *et seq.*

† For a fuller discussion of the pathology of Asphyxia, see the "Cyclop. of Anat. and Phys.," art. 'Asphyxia,' by Prof. Alison; the "Library of Practical Medicine," vol. iii., art. 'Asphyxia,' by the Author; the Experimental Essay by Dr. J. Reid, 'On the Order of Succession in which the Vital Actions are arrested in Asphyxia,' in the "Edinb. Med. and Surg. Journ.," 1841, and in his "Anat., Physiol., and Pathol. Researches;" and the Experimental Inquiry by Mr. Erichsen, in the "Edinb. Med. and Surg. Journ.," 1845.

so much of its oxygen, as to be rendered utterly unfit for the continued maintenance of the aerating process; so that the individual who continues to respire it, shortly becomes asphyxiated. There are several well-known cases, in which the speedy death of a number of persons confined together has resulted from neglect of the most ordinary precautions for supplying them with air. That of the "Black Hole of Calcutta," which occurred in 1756, has acquired an unenviable pre-eminence, owing to the very large proportion of the prisoners—123 out of 146—who died during *one night's* confinement in a room 18 feet square, only provided with two small windows; and it is a remarkable confirmation of the views formerly stated (§ 205), and presently to be again adverted-to, that of the 23 who were found alive in the morning, many were subsequently cut-off by 'putrid fever.' Such catastrophes have occurred even in this country, from time to time, though usually upon a smaller scale; there has happened one at no distant date, however, which rivalled it in magnitude. On the night of the first of December, 1848, the deck-passengers on board the Irish steamer Londonderry were ordered below by the Captain, on account of the stormy character of the weather; and although they were crowded into a cabin far too small for their accommodation, the hatches were closed-down upon them. The consequence of this was, that out of 150 individuals, no fewer than 70 were suffocated before the morning.

301. It cannot be too strongly impressed upon the Medical practitioner, however, and through him upon the Public in general, that the continued respiration of an atmosphere charged in a far inferior degree with the exhalations from the Lungs and Skin, is among the most potent of all the 'predisposing causes' of disease, and especially of those *zymotic* diseases whose propagation seems to depend upon the presence of fermentible matter in the blood. That such is really the fact, will appear from evidence to be presently referred-to; and it is not difficult to find a complete and satisfactory explanation of it. For, as the presence of even a small percentage of Carbonic acid in the respired air is sufficient to cause a serious diminution in the amount of carbonic acid thrown-off and of oxygen absorbed (§ 287), it follows that those oxidating processes which minister to the elimination of effete matter from the system, must be imperfectly performed, and that an accumulation of substances tending to putrescence must take place in the blood. Hence there will probably be a considerable increase in the amount of such matters in the pulmonary and cutaneous exhalation; and the unrenewed air will become charged, not only with carbonic acid, but also with organic matter in a state of decomposition, and will thus favour the accumulation of both these morbific substances in the blood, instead of effecting that constant and complete removal of them, which it is one of the chief ends of the respiratory process to accomplish.—It has been customary to consider the consequences of imperfect respiration, as being exerted merely in promoting an accumulation of Carbonic acid in the system, and in thus depressing the vital powers, and rendering it prone to the attacks of disease. But the deficiency of Oxygenation, and the consequent increase of putrescent matter in the body, must be admitted as at least a concurrent agency; and when it is borne in mind that the atmosphere in which a number of persons have been confined for some time, becomes actually

offensive to the smell in consequence of the accumulation of such exhalations, and that (as will presently appear) this accumulation exerts precisely the same influence upon the spread of zymotic disease, as that which is afforded by the diffusion of a sewer-atmosphere through the respired air, it scarcely admits of reasonable doubt, that the pernicious effect of over-crowding is exerted yet more through its tendency to promote putrescence in the system, than through the obstruction it creates to the due elimination of Carbonic acid from the blood. For it is to be remembered, that whilst the *complete* oxidation of the effete matters will carry them off by the lungs in the form of Carbonic acid and water, leaving urea and other highly-azotized products to pass-off by the kidneys, an *imperfect* oxidation will only convert them into those peculiarly offensive products which characterize the fæcal excretion (§ 104).* The views here expressed have received a remarkable confirmation from the results of the extensive series of investigations undertaken by Pettenkofer and Voit,† who have observed that no discomfort was experienced from long exposure to an atmosphere containing 10 parts of Carbonic acid in 1000 parts, providing this had been added to the air in a pure state; but if the same quantity were present as a result of the respiration of several people, serious inconvenience was soon felt. The proportion of Carbonic acid present in the air of large towns has been examined by Dr. Roscoe‡ and by Dr. Angus Smith.§ Dr. Roscoe found the usual proportion of Carbonic acid in the air of London to be 3·7 parts in 10,000; whilst the proportion in Manchester, according to Dr. Smith, was 12 parts in 10,000 on a still day, and from 4·5 to 8 parts in 10,000 on a windy day. From experiments made with permanganate of potash, he ascertained that on the high grounds north of Manchester there existed but 1 grain of organic matter in 200,000 cubic inches of air, whilst in close places in the town there was 1 grain in 8000 cubic inches. The air of sewers, and generally air loaded with organic matters, has an alkaline reaction, from the presence of ammonia and sulphuret of ammonium.

302. Of the remarkable tendency of the Respiration of an atmosphere charged with the emanations of the Human body, to favour the spread of Zymotic diseases, a few characteristic examples will now be given.—All those who have had the widest opportunities of studying the conditions which predispose to the invasion of Cholera, are agreed that *over-crowding* is among the most potent of these; and from the numerous cases in which this was most evident, contained in the "Report of the General Board of Health" on the epidemic of 1848-9, the two following may be selected.—In the autumn of 1849, a sudden and violent outbreak

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* It is a remarkable confirmation of Prof. Liebig's analogy between the imperfect oxidation of effete matters within the body, and that combustion in a lamp or furnace insufficiently supplied with air which causes a deposit of soot and various empyreumatic products, that a set of acids have been found by Stadeler in the urine of the cow, bearing a close analogy to well-known products of destructive distillation, and one of them actually identical with the *carbolic acid* previously known as one of the ingredients of smoke.—See Prof. Gregory's "Handbook of Organic Chemistry," p. 450.

† An abstract of these will be found in the "Med. Times and Gaz." for Nov. 1, 1862, p. 459.

‡ "Quarterly Journal of the Chemical Society," 1857; and "Med.-Chir. Review," 1861, p. 429.

§ "On the Air of Towns," quoted in "Med.-Chir. Rev.," 1861, vol. ii. p. 433.

of Cholera occurred in the Workhouse of the town of Taunton; no case of cholera having either previously existed, or subsequently presenting itself, among the inhabitants of the town in general, although diarrhœa was prevalent to a considerable extent. The building was altogether badly constructed, and the ventilation deficient; but this was especially the case with the school-rooms, there being only about 68 cubic feet of air for each girl, and even less for the boys. On Nov. 3, one of the inmates was attacked with the disease; in ten minutes from the time of the seizure, the sufferer passed into a state of hopeless collapse; within the space of forty-eight hours from the first attack, 42 cases and 19 deaths took place; and in the course of one week, 60 of the inmates, or nearly 22 per cent of the entire number, were carried-off, while almost every one of the survivors suffered more or less severely from cholera or diarrhœa. Among the fatal cases were those of 25 girls and 9 boys; and the comparative immunity of the latter, notwithstanding the yet more limited dimensions of their school-room, affords a remarkable confirmation of the general doctrine here advanced; for we learn that, although "good and obedient in other respects, they could not be kept from breaking the windows," so that many of them probably owed their lives to the better ventilation thus established. Now in the Gaol of the same town, in which every prisoner is allowed from 819 to 935 cubic feet of air, and this is continually being renewed by an efficient system of ventilation, there was not the slightest indication of the epidemic influence.*—The other case to be here cited, is that of Millbank Prison, in which the good effects of the diminution of previous overcrowding were extremely marked. In the month of July, 1849, when the epidemic was becoming general and severe in the Metropolis (especially in those low ill-drained parts on both sides of the river, in the midst of which this prison is situated), the number of *male* prisoners was reduced, by the transfer of a large proportion of them to Shorncliff barracks, from 1039 to 402; the number of *female* prisoners, on the other hand, not only underwent no reduction, but was augmented from 120 to 131. Now the Cholera-mortality of London generally, which was 0·9 per 1000 in June and July, *increased* to 4·5 per 1000 in August and September; and the mortality among the *female* prisoners underwent a similar *increase*, from 8·3 to 53·4 per 1000; but the mortality among the *male* prisoners exhibited the extraordinary *diminution*, from 23·1 per 1000, which was its rate during June and July when the prison was crowded, to 9·9 per 1000, which was its rate during August and September after the reduction had taken place.† It is scarcely possible to imagine a more *probative* case than this; since it shows, in the first place, the marked influence of the crowded state of the prison upon the fatality of the disease,—secondly, the diminution of mortality among the male prisoners, consequent upon the relief of the overcrowding, notwithstanding the quintupling of the general mortality of the Metropolis during the same period,—and thirdly, the yet greater increase of mortality among the female prisoners, which proved that the diminution among the males could not be attributed to any recession of the epidemic influence from the locality.

303. The cholera-experience of the Indian army is fertile in examples

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* Op. cit., pp. 37 and 71.

† Op. cit., App. B, p. 67.

of the same kind, whose peculiar character makes them even more remarkable. It is to be remembered that the normal amount of Respiration is much lower in a hot, than in a temperate climate (§§ 143, 287); consequently, any deficiency of oxygenation will tend in a yet higher degree to promote the accumulation of putrescent matter in the system, and this especially when there has been any unusual source of 'waste,' such as that induced by excessive muscular exertion.—The circumstances attendant upon the outbreak of Cholera, in 1846, at Kurrachee in Scinde, in which *ten per cent* of an army of 6380 men were carried-off, place the influence of these conditions in a very striking point of view. In order that the comparison may be fairly made, the data specified in the following Table will be taken only from European regiments, similar to each other in diet, clothing, regimen, habits, and every other conceivable particular, save such as will be mentioned:—

Designation.	Strength.	Deaths.	Deaths per 1000.	Exposure at Drill, &c.	Provision for Respiration.	Previous Exertion.
Officers' Ladies .	42	0	0	Nil	Good	Nil.
Officers . . .	200	3	15	Ordinary	Mostly good	Nil or slight.
Horse Brigade .	135	5	37	Ordinary	Good	Moderate.
60th Rifles . .	980	75	76·5	Ordinary	Bad	Nil.
Artillery . .	375	37	96·6	Ordinary	Good	Severe.
Bombay Fusiliers	764	83	108·6	Ordinary	Very bad	Nil.
Soldiers' Wives .	159	23	144·6	Nil	Mostly very bad	Partly severe.
Do. of 86th Regt.	—	—	166·6	Nil	Very bad	Very severe.
86th Regiment .	1091	238	218	Ordinary	Very bad	Very severe.
	3746	464	124			

Now most of the Officers, and all the Ladies, were quartered in well-ventilated apartments; and the only predisposing cause from which the former could be considered as liable to suffer, was the exposure, in common with the soldiers, to the burning heat during the hours of drill. Of the 9 officers attacked with cholera, of whom 3 died (only one of the fatal cases being an uncomplicated one), 4 belonged to the Bombay Fusiliers, and had been living (like their men) in tents. The Horse Brigade were lodged in good barracks, but had recently come off a march of 1000 miles; being mounted, however, they must have suffered comparatively little fatigue from this. The 60th Rifles were quartered in barracks; but the ventilation of these was very imperfect, and the men were much crowded. The battalions of Artillery were quartered in good barracks; but three out of the four had recently made the march of 1000 miles on foot. The Bombay Fusiliers were quartered in tents, whose accommodation was so limited, that 10 or 12 men were cooped-up in a space 14 feet square, with the thermometer ranging from 96° to 100°, and without any adequate provision for ventilation. The 86th Regiment was quartered in precisely the same manner; and had recently made the march of 1000 miles under very unfavourable circumstances, besides having previously suffered from the debilitating influence of severe service. The condition of the Soldiers' Wives as regards their accommodation would be the same as that of their husbands, but they would not be subjected to the fatigue and exposure of drill; on the other hand, their fatigue and exposure during a march would be scarcely inferior to that of the men; and it was among the women, as among the soldiers, of the 86th Regiment, that the chief mortality occurred, their loss having been 1 in 6, or 166·6 per 1000.—Thus we see that the *highest* rate of mortality presents itself, where the three causes were in concurrent action; the *absence* of mortality, where neither of them was in operation. The difference between the mortality of the Bombay Fusiliers (108·6 per 1000) and that of the 86th Regiment (218 per 1000), which were under precisely the same conditions as regards exposure and ventilation, shows the extraordinary influence of previous exertion; but that this would not of itself account for the high rate of mortality in the 86th, is shown by the smaller proportion of deaths in the Artillery; the influence of the same march upon three out of its four battalions, having been in a great degree kept-down by the adequate provision for their respiration, so that their mortality was less than that of the Bombay Fusiliers, who had not suffered from previous exertion, but were overcrowded in ill-ventilated tents.—It is scarcely possible to imagine any more satisfactory proof of the *preventibility* of a large part of this terrible mortality, than is afforded by the analysis of this case;* but if any confirmation be required, it is afforded by the case of Bellary, a fortress about 250 miles north-west of Madras. Although by no means unhealthily situated, this station was not free from Cholera for a single year between 1818 and 1844; and violent outbreaks took place occasionally, such as that of 1839, in which the 39th Regiment was reduced in five months from 735 men to 645, the number of deaths being 90, or 122½ per 1000. The barrack-accommodation in this fort was extremely insufficient for the garrison regularly quartered in it; yet small as it was, it was occasionally encroached-upon still further by the introduction of troops upon their march; and after such occasions of special overcrowding, a large increase in the mortality almost invariably occurred. But since the barrack-accommodation has been improved, the troops quartered at Bellary have ceased to suffer from cholera in any exceptional degree, and the ordinary rate of mortality has been considerably diminished.

304. The only condition of atmosphere which can be compared with that arising from overcrowding, in its effect upon the spread of Cholera, is that produced by the diffusion of the effluvia of drains, sewers, slaughter-houses, manure-manufactories, &c., which correspond closely in their nature and effects with the putrescent emanations from the living Human body. So remarkably has the localization of the disease shown itself to be connected with this condition, that the knowledge of the existence of the latter makes it safe to predict the former; such a prediction being scarcely ever falsified by the result.—As a characteristic illustration of the operation of this cause, the outbreak of Cholera at Albion-terrace, Wandsworth-road, in 1849, may be specially referred-to. This place consisted of 17 houses, having the appearance of commodious middle class dwellings; the population does not seem to have averaged more than 7 individuals per house, so that there was no overcrowding; yet out of the total 119 or 120, no fewer than 42 persons were attacked

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* For a fuller statement of it, see the "Brit. and For. Med.-Chir. Rev.," vol. ii. pp. 81-89.

with cholera, of whom 30 (or 25 per cent) died. It was not difficult to account for this fearful result, when the circumstances of the case were inquired-into. About 200 yards in the rear of the terrace was an open sewer, whose effluvia were most offensive at the backs of these houses, whenever the wind wafted them in that direction; and the drainage of the houses themselves was so bad, that a stench was continually perceived to arise from different parts of the kitchen-floor, and more especially from the back-kitchen. Moreover, in the house in which the first case of cholera occurred, there was an enormous accumulation of most offensive rubbish, exhaling a putrid effluvium. And there was also reason to believe, that the water supplied to some of the houses had accidentally become contaminated with the contents of a sewer and cesspool.*—The accumulation of night-soil and other rubbish in a triangular space of about three acres in Witham, a suburb of Hull, had been represented to the local authorities as almost certain to induce a severe outbreak of cholera in the neighbourhood; the prediction was disregarded; but it was most fearfully verified by the occurrence of no fewer than 91 deaths in its immediate neighbourhood.†—Numerous examples of the same kind might be cited; but the following shows the efficacy of preventive measures. The Coldbath-fields House of Correction, situated in the neighbourhood of some of the most overcrowded and ill-drained parts of the metropolis, had suffered severely from Cholera in the epidemic of 1832-3; for out of 1148 prisoners, 207 were attacked with cholera, of whom 45 died, and 319 more suffered from diarrhœa. At that period, however, it was discovered that the whole drainage of the prison was in a most defective state, and steps were taken to have it completely and effectually renewed; at the same time the diet was somewhat improved, and more attention was paid to temperature and ventilation. In the epidemic of 1848-9, with 1100 prisoners, there was not a single case of cholera in this prison, although the disease was raging in its vicinity; and the cases of diarrhœa were few in number, and were mild in their character.‡

305. The Cholera-experience of the United States, during the Epidemic of 1849-50,§ afforded some of the most striking examples that have been anywhere displayed, both of the dire effects of neglect, and of the complete efficacy of preventive measures. The contrast is well shown in the manner in which the epidemic affected the town of Louisville, in Kentucky; which is situated by the Ohio river, on a plateau about 70 feet above low-water-mark, composed of sand and river-gravel, intermingled with tenacious clay, and reposing on a friable shale. This compound is peculiarly tenacious of moisture; and large ponds formerly existed, in the midst of which the first houses were built. While this state of things continued, Louisville was one of the most sickly towns in the Mississippi valley, and was commonly termed "the graveyard of the West." Intermittent fever was a regular visitant; and epidemics of fever of other types frequently raged with great severity. Thus, in

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* "Report of the General Board of Health on the Epidemic Cholera of 1848-9," p. 43.

† Op. cit., p. 45.

‡ Op. cit., App. B, p. 68.

§ See the 'Abstract of Report by James Wynne, M.D., on Epidemic Cholera, as it prevailed in the United States in 1849 and 1850;' constituting "Appendix C to the Report of the General Board of Health on the Epidemic Cholera of 1848-9."

the summer of 1822, after a hot rainy season, 232 persons died of bilious fever, out of a population of about 5000; in a family consisting of 20 persons, 19 were sick at one time, and in some families every individual died. At this period, only one street in Louisville was paved; and within its limits were at least eight ponds of greater or less dimensions, most of which, in the course of the autumn, were dried-up, exposing foul bottoms to the sun. Previously to the Cholera-epidemic of 1832-3, its condition had been somewhat improved; still the principal part of the town suffered severely. Much more, however, has been subsequently effected; so that from being reputed one of the most unhealthy towns in the west, Louisville has come to be esteemed one of the most healthy: at the same time its population has increased from 10,000 in 1830, to 50,000 in 1850. Entire squares are now pointed-out, which occupy the beds of ponds once large and deep enough to float a steamboat. Still much of the lower part of the city is in a very foul condition; the ground on which it is built being saturated with water to a considerable depth after heavy rains, and being also the receptacle of the filthy washings of the more elevated portion; besides having many nuisances of its own, especially accumulations of decaying hemp-offal. It was in this part that Cholera first made its appearance in 1849, in the identical square in which the earliest cases had appeared in 1832; and to this part it was almost entirely restricted. "*Those places in Louisville*," says the Medical Reporter, "*which bore the brunt of the Cholera in* 1833, *and which have been improved so as to be dry, clean, and airy, have been as free from Cholera as from the oriental plague. But those places in this city which were scourged in* 1833, *and which remain now in the state they were in then, have been scourged again in* 1849-50."

306. A yet more remarkable contrast is presented by the comparative experience of the City and of the Almshouse of Baltimore. During the spring of 1849, when, from the prevalence of Cholera in the great towns to the north, it appeared next to certain that the epidemic would visit Baltimore, not only its public authorities, but its citizens generally, exerted themselves with commendable zeal to ward-off its severity by active measures of sanitary purification. Although in many respects superior to the average of large towns, Baltimore was by no means free from those collections of filth invariably found to a greater or less extent among the most degraded portion of their population; and of the evil results of these, the constant presence of typhoid fever, among the miserable coloured inhabitants of its worst localities, had long furnished a standing proof. During the summer months, when the city was completely surrounded by the Choleraic atmosphere, diarrhœa and kindred affections became very prevalent in Baltimore; and Dr. Wynne further mentions, as of universal occurrence in those who had not a positive attack of diarrhœa, "an undefinable sense of oppression, not amounting to pain, over the whole region of the abdomen, reminding a person constantly of the existence of such a part of the body." This state of things impressed the Medical authorities with the belief that the Cholera-poison was brooding over the town, and that an outbreak might be continually expected. Yet it entirely passed away, without giving rise to more than *four* attacks of genuine Cholera; two of these being in the persons of Germans, who occupied a wretched tenement in a very filthy condition; the third case being that of a man,

whose sleeping apartment looked-out upon an alley which had been suffered to remain in a very foul state; whilst the fourth, which occurred in the largest and most fashionable hotel in the city, was obviously an imported case.—Yet, as if for the very purpose of demonstrating that the immunity which the city itself enjoyed, was entirely due to the sanitary precautions which its inhabitants had so wisely taken, a fearful outbreak of Cholera took place in the Almshouse, only two miles out of town, which proved fatal to 99 persons out of a population of 632, or *nearly one in six;* and it was only kept within this limit, by the promptness with which the sources of this terrible mortality were removed, when once they had been discovered.

307. The circumstances of this outbreak were so peculiar as to need a somewhat detailed description.—The main building of the Almshouse was originally the country seat of a wealthy citizen, who erected a costly mansion on an elevated site which he had specially chosen for its beauty and healthfulness; it had subsequently been much enlarged, for the accommodation of its six or seven hundred inmates; but it still remained entirely isolated, being surrounded by a farm of 200 acres, for the most part devoted to cultivation. From the original centre, two principal wings extended on either side, one for the male and the other for the female side, forming an extensive range of building, whose front had a southern aspect, whilst the back looked towards the north. Behind this were other wings running north and south, with various offices, spread over an area of about 4½ acres, which was enclosed by a wall. Like the city itself, the Almshouse had received a thorough purification, under the superintendence of the visiting physician; whose directions, as regarded ventilation and internal cleanliness, seem to have been strictly complied with. Nevertheless an unequivocal case of Cholera presented itself on July 1st, another on July 7th, four more during the ensuing week, and on July 14th *thirteen* of the inmates were attacked at once. All the patients were old inhabitants of the establishment, and had unequivocally contracted the disease on the spot; but although fully impressed with the conviction that some special cause must exist for this rapidly-increasing mortality, the visiting physician did not succeed in detecting it until the 19th, when he extended his survey, for the first time, beyond the enclosure. He then discovered that the whole triangular space included between its posterior boundary-wall, and a ravine which approached within nine feet of its western angle, but which was separated from its eastern angle by an interval of about seventy feet, was *one putrid and pestilential mass,* capable of generating, under the ardent rays of a midsummer sun, the most poisonous emanations; for although the ravine was admirably adapted to carry-off the drainage of the establishment, this had never been properly conducted into it; the overflowings of cesspools, pigsties, &c., having been allowed to spread themselves over the intervening area, which they kept, of course, in a state of constant pollution, superficially concealed by a rank weedy vegetation. Some difficulty was experienced in procuring men to remove this nuisance, so that it remained untouched till the 23rd. The pools of filth were then drained by trenches into the ravine, and were washed-out by a stream of fresh water; lime was spread over the whole surface; and this again was covered with a thick layer of earth. The men employed in this work were attacked with Cholera, but

recovered. *The day after it was completed*, the number of cases in the Almshouse suddenly dropped from *eleven* to *three;* and within a fortnight more, the disease had entirely disappeared.—But this is by no means all. The attacks of Cholera were far from being uniformly distributed through the building, but were almost exclusively restricted to those parts of it which were directly exposed to the emanations conveyed from this pestilential spot, by the northerly wind which blew steadily during the whole time of the prevalence of the disease. Thus, in the centre building, the Manager, who slept in a room looking to the *north*, was attacked, but recovered; among his family, whose rooms looked to the *south*, no case of the disease occurred. Four medical students who occupied rooms beneath that of the Manager, and with the same exposure, were attacked, but recovered; four others, lodged in similar rooms with a southern exposure, entirely escaped. The apothecary and coach-driver, who occupied rooms in the men's wing with windows opening to the north, were both attacked, but both recovered. Among the pauper inmates of the wings, those generally were seized who slept in the northern wards; and it was observable that the male side suffered generally much more severely than the female,—a difference not attributable to anything in the building or its inhabitants, but at once explained by the fact, that whilst no barrier existed between the male side and the putrid marsh, the female wing was protected from the pestilential current by three intervening rows of trees.* On the female side, however, a building ran in a north and south direction, of which the lower storey had a door in the north, opening quite near the putrid marsh, whilst the upper storeys had only a blank wall at this end; this lower storey was tenanted by *seventeen lunatics, all of whom were attacked with Cholera, and all died*, whilst not a single attack of Cholera took place among the inmates of its upper storeys. And in addition, it was noticed that the removal of the Cholera patients to the ward above the black people's hospital, where the miasmatic influence was entirely unobstructed, was attended with a marked aggravation of their malady.

308. Now although the Cholera-epidemics have been here referred-to, as affording the most remarkable examples of the influence of a contaminated atmosphere in predisposing the individuals habitually living in it to the invasion of Zymotic disease, yet the evidence is not less strong in regard to the uniform prevalence of ordinary Fevers, &c., in the same localities; the places in which Cholera was the most severe, having been almost invariably known as 'fever-nests' in other periods, and being distinguished by a very high rate of mortality. Thus the average age of all persons who die in Witham is only 18 years; whilst the average age at death in the town of Hull (itself distinguished by an unusual brevity of life) is 23 years.—In the 'Potteries' at Kensington, a locality in which filth and overcrowding prevail to an almost unequalled degree, the mortality for three years previously to the invasion of Cholera had been such

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* These probably acted not merely mechanically, by obstructing the current, but also chemically by decomposing or oxidating the noxious emanations. For it has been frequently remarked, that a screen or belt of umbrageous trees effectually secures the dwellers on the borders, and even on the leeward side, of the most pestiferous marshes, from the effects of their malaria. How far they have the same influence on *animal* effluvia, we are not yet in a position to state.

that the average age at death was only 11 yrs. 7 mo.; and in the *first ten months* of 1849, out of a population of about 1000, there were 50 deaths, of which 21 were from cholera and diarrhœa, and 29 from typhus fever and other diseases. It is illustrative of the common points between cholera and other zymotic diseases, that the former appeared there not only in the same streets and in the same houses, but even in the same rooms, which had been again and again visited by typhus; and there were several tenants of such rooms, who only recovered from fever in the spring, to fall victims to cholera in the summer. Subsequently to this epidemic, the average age at death has been further reduced, by an increase of infantile mortality, to as low as 10 years.—By way of contrast, it may be stated that in one of the "Model Lodging-Houses," containing about 550 inmates, among whom was an unusually large proportion of children, the rate of mortality during the three years ending May, 1851 (including the whole period of the cholera-epidemic), was scarcely more than 20 in 1000; the proportion of deaths under ten years of age was only half that of the metropolis in general; there was not a single attack of cholera, and there were only a few cases of choleraic diarrhœa, although the disease was raging in the immediate vicinity; and from the time that the sewerage had been put into complete order, typhus fever had entirely disappeared, a few cases having occurred soon after the opening of the buildings, which were distinctly traceable to a defect in the drainage.*—The following case may be added, in proof of the potency of an atmosphere charged with putrescent emanations, in rendering the system liable to the attacks of Zymotic diseases of various kinds. A manufactory of artificial manure formerly existed immediately opposite Christchurch workhouse, Spitalfields, which building was occupied by about 400 children, with a few adult paupers. Whenever the works were actively carried-on, particularly when the wind blew in the direction of the house, there were produced numerous cases of fever, of an intractable and typhoid form; a typhoid tendency was also observable in measles, small-pox, and other infantile diseases, and for some time there prevailed a most unmanageable and fatal form of aphthæ of the mouth, ending in gangrene. From this last cause alone, 12 deaths took place among the infants in three months. In the month of December, 1848, when cholera had already occurred in the neighbourhood, 60 of the children in the workhouse were suddenly seized with violent diarrhœa in the early morning. The proprietor was compelled to close his establishment, and the children returned to their ordinary health. Five months afterwards, the works were recommenced; in a day or two subsequently, the wind blowing from the manufactory, a most powerful stench pervaded the building. In the night following, 45 of the boys, whose dormitories directly faced the manufactory, were again suddenly seized with severe diarrhœa; whilst the girls, whose dormitories were in a more distant part, and faced in another direction, escaped. The manufactory having been again suppressed, there was no subsequent return of diarrhœa.†

309. It may not be amiss to add a few examples drawn from the

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* Op. cit., App. B, pp. 48 and 77; and Mr. Grainger's subsequent "Report on the present state of certain parts of the Metropolis, and on the Model Lodging-Houses of London," pp. 29, 36.

† "Report of the Board of Health on Cholera, 1848-9," p. 42.

experience which our Indian possessions have afforded, of the influence of an insufficient supply of pure air upon the *ordinary mortality* in our army and among the people under our control.—There are various military stations, which have lain under a most ill-deserved repute for unhealthiness, in consequence of the very imperfect barrack-accommodation afforded to the troops quartered in them. Thus at Secunderabad, in the Madras command, the average annual mortality for the fifteen years previous to 1846-7, was 75 per 1000; this being *nearly double* the average of the whole presidency, and *more than double* that of the remainder of the stations. Now the complaints made year after year, by the medical officers of the troops which have been successively quartered at this station, leave no room for doubt as to the chief cause of this excess; for the regiments of the Line quartered at Secunderabad have been always crowded in barracks quite insufficient for their accommodation, one-third of the men having been obliged to sleep in the verandahs, and the remainder getting by no means a due allowance of fresh air; whilst, on the other hand, the Officers of these very regiments, who are better accommodated, and the detachment of Artillery quartered in more roomy barracks at no great distance, have never participated in this unusual mortality, thereby clearly showing the absence of any special causes of disease at this station, which might not be easily removed.*—The Barrackpore station, in the Bengal command, is even worse than the foregoing; for every regiment quartered there, seems to suffer an almost complete *decimation* annually. Yet there is ample evidence, that here also the chief fault lies in the barrack-accommodation.—But one of the most terrible instances of the continuance of a high rate of mortality, which is almost entirely attributable to an insufficient supply of air, is that which is furnished by the Gaols under British control in India. In these are usually confined no fewer than 40,000 prisoners, chiefly natives; and the average annual mortality of the whole was recently 10 per cent, rising in some cases to 26 per cent, or more than *one in four*. This is easily accounted-for, when it is known that in no case is there an allowance of more than 300 cubic feet of air-space for each individual, whilst in some instances 70 cubic feet is the miserable average !†

310. One more set of cases will be cited, as showing the marked effect of the habitual respiration of a contaminated atmosphere, not merely in engendering a liability to zymotic disease, but in directly producing a special form of infantile spasmodic disease, of the most fearful nature.—The dwellings of the great bulk of the population of Iceland seem as if constructed for the express purpose of poisoning the air which they contain. They are small and low, without any direct provision for ventila-

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* It is a remarkable confirmation of the view formerly stated (§ 52), as to the tendency of the habitual use of Alcoholic liquors to induce a 'fermentible' condition of the blood, by obstructing the elimination of the effete matters by the respiratory process, that when the 84th Regt., which is distinguished for its sobriety, was quartered at Secunderabad in 1847-8, it lost only 39 men out of 1139, or 34·2 per 1000, the average mortality of the other stations in the Presidency being about the same as usual. On the other hand, the 63rd Regt., which was far from deserving a reputation for temperance, had lost 73 men during the first nine months of the preceding year, or at the rate of 78·8 per 1000 during the entire year.—All the facts here stated in regard to Secunderabad have been obtained by the Author direct from the Army Medical Returns.

† Dr. Mackinnon's "Treatise on the Public Health, &c., of Bengal," Cawnpore, 1848, chap. i.

tion, the door serving alike as window and chimney; the walls and roof let-in the rain, which the floor, chiefly composed of hardened sheep-dung, sucks-up; the same room generally serves for all the uses of the whole family, and not only for the human part of it, but frequently also for the sheep, which are thus housed during the severer part of the winter. The fuel employed in the country districts chiefly consists of cow-dung and sheep-dung, caked and dried; and near the sea-coast, of the bones and refuse of fish and sea-fowl; producing a stench, which, to those unaccustomed to it, is completely insupportable. In addition to this, it may be mentioned that the people are noted for their extreme want of personal cleanliness; the same garments (chiefly of black flannel) being worn for months without being even taken-off at night. Such an assemblage of unfavourable conditions, combined with the cold damp nature of the climate, might have been expected to induce tubercular diseases of various kinds; but from these the Icelanders appear to enjoy a special exemption (§ 46, III.). Syphilis, also, is wanting, or nearly so; and yet, notwithstanding that the number of births is fully equal to the usual average, the population is stationary, and in some parts actually diminishing. This is partly due to the extent and fatality of the epidemic diseases, of which some one or other spreads through the island nearly every year; but it is chiefly owing to the extraordinary mortality of infants from *Trismus nascentium*, which carries-off a large proportion of them between the fifth and the twelfth days after their birth. It is in the little island of Westmannoe and the opposite parts of the coast of Iceland, where the bird-fuel is used all the year round, instead of (as elsewhere) during a few months only, that this disease is most fatal; the average mortality for the last twenty years, during the first twelve days of infantile life, being no less than 64 per cent, or nearly *two out of three.**—Now it is not a little remarkable that the very same disease should have prevailed, under conditions almost identically the same, in the island of St. Kilda, one of the Western Hebrides; the state of which was made known by Mr. Maclean, who visited it in 1838. The population of this island, too, was diminishing rather than increasing, in consequence of the enormous infantile mortality; *four out of every five* dying, from Trismus nascentium, between the eighth and twelfth days of their existence. The great if not the only cause of this mortality, was the contamination of the atmosphere by the filth amidst which the people lived. Their huts, like those of the Icelanders, were small, low-roofed, and without windows; and were used during the winter as stores for the collection of manure, which was carefully laid-out upon the floor, and trodden under foot to the depth of several feet. On the other hand, the clergyman, who lived exactly as did those around him, except as to the condition of his house, had brought-up a family of four children in perfect health; whereas, according to the average mortality around him, at least three out of the four would have been dead within the first fortnight.—Of the degree in which this fearful disease is dependent upon impurity of the atmosphere, and is preventible by adequate ventilation, abundant proof is afforded by the experience of Hospitals and Workhouses in our own country. Thus in the Dublin Lying-in Hospital, up to the year 1782, the mortality within the first fortnight, almost entirely from Trismus nascentium, was 1 in every 6 children born. The adoption, under the direction of Dr. Joseph Clarke, of an improved system of ventilation, reduced the proportion of deaths from this cause to 1 in 19½. And further improvements in ventilation, with increased attention to cleanliness, during the seven years in which Dr. Collins was Master of this Institution, reduced the number of deaths from this disease to no more than three or four yearly.*—A similar amelioration took place about a century ago, in the condition of the London Workhouses, in which 23 out of 24 infants had previously died within the first year, and a large proportion of these within the first month; for owing to a parliamentary inquiry which was called-forth by this fearful state of things, the proportion of deaths was speedily reduced (chiefly by improvement in ventilation) from 2600 to 450 annually.

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* See "Island undersögt fra lægevidenskabeligt Synspunct." Af P. A. Schleisner, M.D.—Copenhagen, 1849.

311. Thus it appears that in all climates, and under all conditions of life, the *purity of the atmosphere* habitually respired is essential to the maintenance of that power of resisting disease, which, even more than the ordinary state of health, is a measure of the real vigour of the system. For, owing to the extraordinary capability which the human body possesses of accommodating itself to circumstances, it not unfrequently happens that individuals continue for years to breathe a most unwholesome atmosphere, without apparently suffering from it; and thus, when they at last succumb to some Epidemic disease, their death is attributed solely to the latter; the previous preparation of their bodies for the reception and development of the zymotic poison, being altogether overlooked. It is impossible, however, for any one who carefully examines the evidence, to hesitate for a moment in the conclusion, that the fatality of Epidemics is almost invariably in precise proportion to the degree in which an impure atmosphere has been habitually respired; that an atmosphere loaded with putrescent miasmata may afford a *nidus* wherein a zymotic poison undergoes a marked increase in quantity and intensity, the putrescent exhalations from the lungs and skin of the living subject being at least as effectual in furnishing such a 'nidus,' as are the emanations from fæcal discharges or from other decomposing matters; that the habitual respiration of such an atmosphere tends to induce a condition of the blood, which renders it peculiarly susceptible of perversion by the introduction of zymotic poisons, and which favours their multiplication within the system;† and lastly, that by due attention to the various means of promoting atmospheric purity, and especially by efficient ventilation and sewerage, the rate of mortality may be enormously decreased, the amount and severity of sickness lowered in at least an equal proportion, and the fatality of Epidemics almost completely annihilated. The effects of good

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* See Dr. Collins's "Practical Treatise on Midwifery," p. 513.

† A careful consideration of the very satisfactory evidence which has been of late years collected on this point, must (in the Author's opinion) satisfy any *competent* and *unprejudiced* inquirer, that Endemic Fevers, originating in local causes (marsh miasmata and the like), and at first affecting those only who are exposed to such causes, may find, by the crowding-together of infected subjects, a *nidus* for development within the Human system; so that these diseases *then* become communicable by human intercourse, although not so originally.—For a discussion of this subject, see the Articles on 'Yellow Fever' and the 'Fever of Boa Vista,' in the "Brit. and For. Med.-Chir. Rev.," vols. i. ii. and iv.

drainage and water-supply have been recently well exemplified in the case of Salisbury: the average number of deaths for the eight years preceding the completion of the drainage in this town (excluding the Cholera year) having been 27 in 1000, and for the same period since 21 in 1000; an actual reduction of almost one-fourth of the whole number.* And it cannot be too strongly borne in mind, that the efficacy of such *preventive* measures has been most fully substantiated, in regard to many of the very diseases in which the *curative* power of Medical treatment has seemed most doubtful; as for example, in Cholera and Malignant Fevers.—The practical importance of this subject may be estimated from the startling fact, which inquiries prosecuted under the direction of the Board of Health have brought to light;†—viz., that the *difference* in the annual rates of mortality, between the most healthy and the most unhealthy localities in England, amounting to no less than 34 in 1000, is almost entirely due to Zymotic diseases, which might be nearly (if not completely) exterminated by well-devised sanitary arrangements. The *lowest* actual mortality is 11 per 1000, while the *highest* is 45 per 1000; and between these extremes, there is every intermediate degree of range. But what may be termed the *inevitable* mortality,—arising from diseases which would not be directly affected by Sanitary improvements—is a *nearly constant* quantity throughout; namely, the 11 per 1000 of those districts which are free from Zymotic disease. The average mortality of all England, in ordinary years, is about 22 per 1000, or just double that to which it might be reduced; so that, taking the population of England and Wales (as by the last Census) at 20 millions, the average annual mortality must be 440,000, of which only 220,000 is *inevitable*, an equal amount being *preventible.*

CHAPTER VIII.

OF NUTRITION.

1. *General Considerations.—Formative Power of Individual Parts.*

312. THE function of Nutrition, considered in the widest acceptation of the term, includes that whole series of operations by which the alimentary materials,—prepared by the Digestive process, introduced into the system by Absorption, and carried into its *penetralia* by the Circulation,—are converted into Organized tissue: but in a more limited sense it may be understood as referring to the last of these operations only, that of *Histogenesis* or tissue-formation, to which all the other organic functions, in so far as they are concerned in maintaining the life of the individual, are subservient, by preparing and keeping in the requisite state of purity the materials at the expense of which it takes place. Every integral part of the living body possesses a certain capacity for growth and development, in virtue of which it passes through a series of successive phases, under the influence of the steady Heat, which in the warm-blooded animal is

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* See "Times," Oct. 24, 1863.

† See "Summary of Experience on Disease, and Comparative Rates of Mortality," by William Lee, Superintending Inspector, 1851.

constantly acting upon it; this capacity being an endowment which it derives by direct descent from the original germ (CHAP. I.), but undergoing a gradual diminution with the advance of life (CHAP. XVIII.), until the power of *maintenance* is no longer adequate to antagonize the forces that tend to the *disintegration* of the system. It has been also shown (CHAP. V.), that notwithstanding the diversities in the structure and composition of the several tissues, the Blood supplies the materials which each requires; every tissue possessing (so to speak) an *elective affinity* for some particular constituents of that fluid, in virtue of which it abstracts them from it, and appropriates them to its own uses.—But it has been shown, on the other hand, that the 'formative capacity' does not exist in the tissues alone, but is shared by the Blood, which must itself be regarded as deriving it from the original germ; for there are certain simple kinds of tissue, which appear to take their origin directly in its plastic components. Of others, which cannot be said thus to originate in the blood, the development seems to be entirely determined by the quantity of their special *pabula* which it may contain. Thus, an increase of Adipose tissue takes place, when the blood habitually includes an unusual amount of fat; an augmentation in the proportion of the Red Corpuscles of the blood may be distinctly observed (especially if it has been previously diminished unduly), when an additional supply of iron is afforded; and when one of the Kidneys has been removed, or is prevented by disease from performing its normal function, the other, if it remain healthy, undergoes an extraordinary increase in size, so as to perform the duty of both organs, the augmented development of its secreting structure being here also fairly attributable to the accumulation of its appropriate materials in the blood.* Even of those tissues which must be considered as most independent and self-sustaining, the development is not only checked by the want of a due supply of their appropriate materials, but it is modified in a very remarkable degree by the presence of abnormal substances in the blood, which single-out particular parts, and effect determinate alterations in their nutrition, in such a constant manner as to show the existence of a peculiar 'elective affinity' between them.—In so far, then, as the process of Nutrition is dependent upon the due supply and normal state of the Blood, its conditions have been already sufficiently discussed; and we have now only to consider it in its relations to the Tissues.

313. The demand for Nutrition primarily arises from the tendency of

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* This principle is one most fertile in Pathological applications; for there can be little doubt that the development of many morbid growths is due, not so much to a perverted local action, as to the presence of certain morbid matters in the blood, which determines the formation of tissues that use them as their appropriate pabulum. Such is pretty obviously the case with those disorders, which (like the Exanthemata) are universally admitted to be of 'constitutional' character, and which are distinctly traceable to a poison introduced through the blood, whose first influence is exerted in modifying the physical and vital properties of that fluid: and the evidence has been of late accumulating, that it is true also of the various forms of Cancer, the local development of an abnormal structure being in this case, also, nothing else than the manifestation of the existence of that peculiar matter in the blood, which is the appropriate nutriment of its component tissues; or, as Mr. Simon appropriately designates it, "a new excretory organ, which tends essentially to acts of eliminative secretion, just as distinctly as the healthy liver or the healthy kidney."—See Mr. Simon's "Lectures on General Pathology," pp. 87, 152; and Mr. Paget's "Lectures on Surgical Pathology," vol. i. p. 441, and vol. ii. pp. 528 *et seq.*

the organism to simple *Increase* or *Growth.* Of this we have the most characteristic illustration in the multiplication of the first embryonic cell by the simple process of 'duplicative subdivision;' whereby a multitude of cells is produced, every one of which is similar in all essential particulars to the original. But after the different parts of this homogeneous embryonic mass have taken upon themselves their respective modes of development, so as to generate a diversity of tissues and organs, each one of these continues to increase after its own plan; and thus the child becomes the adult, with comparatively little change but that of growth (CHAP. XVI., Sect. 4). An excess of growth, taking place conformably to the normal plan of the tissue or organ, constitutes *Hypertrophy;* whilst a diminution, without degeneration or alteration of structure, is that which is properly distinguished as *Atrophy.*—But Growth is not confined to the period of increase of the body generally; for it may manifest itself in particular organs or tissues, as a normal operation, at any subsequent part of life; as when an extraordinary demand for the functional activity of a particular set of Muscles is supplied by an increase in the amount of their contractile tissue. —And further, even where there is no such manifestation of increase, there is really a continual growth in all the tissues actively concerned in the vital operations, and this even to the very end of life; although it may be so far counterbalanced, or even surpassed, by changes of an opposite kind, that instead of augmentation in bulk, there is absolute diminution.

314. The evolution of the complete organism from its germ, however, does not consist in mere growth; for by such a process nothing would be produced but an enormous aggregation of simple cells, possessing little or no mutual dependence, like those which constitute the shapeless masses of the lowest Algæ. In addition to increase there must be *Development*, that is, a passage to a higher condition, both of form and structure; so that the part in which this change takes-place becomes fitted for some special function, and is advanced towards the state in which it exists in the highest or most completed form of its specific type. Thus the development of *tissue* consists in the change from a simple mass of cells or fibres into any other form; as in the production of Dentine from the cellular substance of the tooth-pulp, or in the formation of Bone in the sub-periosteal membrane. So, again, the developmental change is seen in the passage of an entire *organ* from a lower to a higher condition, by the evolution of new parts, or by a change in the relations of those already existing, even though the change in its texture should consist of little else than of simple increase: thus in the development of the Heart, we have the original single cavity subdivided, first into two, and at last into four chambers: and in the development of the Brain, we find the sensory ganglia to be the parts first formed, the anterior lobes of the cerebrum to be evolved (as it were) from these, the middle lobes sprouting-forth from the back of the anterior, and the posterior from the back of the middle; yet with all this, there is no production of any new kind of tissue, the new parts being generated at the expense of histological components identical with those of the pre-existing.—Now it is in the early period of embryonic life, that the *developmental* process is most remarkably displayed; for it is then that we see that transformation of the primordial cells into tissues of various kinds, which originates

a special *nisus* in each part, whereby the production of the same tissue, in continuity with that first-formed, comes to be a simple act of growth; and it is then also that we observe that marking-out of all the principal organs, by the development of tissue in particular directions, which makes all subsequent evolution but a completion or filling-up of the plan thus sketched-out. Thus, during the first days of incubation in the Chick, the foundation is laid of the vertebral column, the nervous centres, the organs of sense, the heart and circulating system, the alimentary canal, the respiratory apparatus, the liver, the kidneys, and many other parts; and at the termination of that period, the chick emerges in such a state of completeness of development, that little else than *increase* is wanting, save in the plumage and sexual organs, to raise it to its perfect type. The same may be said of the Human organism; save that the period of its development is relatively longer, in accordance with the higher grade which it is ultimately to attain; its earliest stages being passed-through, however, with extraordinary rapidity. The complete evolution of the generative organs, of the osseous skeleton, and of the teeth, constitute the principal developmental changes which the Human organism undergoes in its progress from the infantile to the adult condition; almost every other alteration consisting in simple increase of its several component tissues and organs, without any essential change in their form or structure. And when the adult type has been once completely attained, every subsequent change is one rather of degeneration than of development, of retrogression rather than of advance.

315. The difference between these two processes of Growth and Development is most characteristically shown in those cases, in which there is a partial or complete arrest of one of them, without any corresponding impairment of the other. Thus a dwarf, however small in stature, may present a perfect development of every part that is characteristic of the complete human organism; the deficiency being solely in the capacity for *growth.* On the other hand, the usual size at birth may be attained, and every organ may present its ordinary dimensions, and yet some important part may be found in a condition of *arrested development:* thus the Heart may consist of a single cavity, or the inter-ventricular or inter-auricular septa may be incomplete, so that the organ has not passed beyond the grade of development which it had attained at an early period of embryonic life, although its growth may have continued; or the Brain may in like manner exhibit a deficiency of the posterior lobes, or of the corpus callosum, or of some other part whose formation nominally takes place in the latter months of intra-uterine life, although the parts already produced may have continued to grow at their usual rate.—Numerous instances of the same kind might be cited, but these must suffice.

316. The demand for Nutrition arises, however, not merely from the exercise of the formative powers which are concerned in the building-up of the organism, but also from the degeneration and decay which are continually taking-place in almost every part of it, and the effects of which, if not antagonized, would speedily show themselves in its complete disintegration. As each component cell of the organism has to a certain degree an independent life of its own, so has it also a limited duration; and its duration usually bears an inverse ratio to its functional

activity. This is particularly striking when we compare the ratio of change in the organisms of cold-blooded animals at low and at high temperatures; for they live slowly, need little nutriment, give-off but a small amount of excretory products, and require a long time for the performance of the reparative processes, under the former condition; but live fast, require a comparatively large supply of nutriment, give-off a far greater amount of carbonic acid and other excretions resulting from the 'waste' of tissue, and exhibit a far more rapid reparation of injuries, in the latter state. The constantly-high temperature of Man, as of other warm-blooded animals, prevents this difference from being displayed in him in a similar manner; but it is well seen when we contrast his different tissues with each other, and study their respective histories. For whilst there are some (I.) which appear to pass through all their stages of growth, maturation, and decline, within a limited period, there are others (II.) whose existence seems capable of almost indefinite prolongation, and others (III.), again, which are liable to have a period put to their life at any time, by the direction of their vital force into other channels.

I. Of those belonging to the first category, which are actively concerned in the purely-*vital* operations of the organism, a characteristic example is presented by the Ovule; which, if not fertilized within a limited period after its maturation, speedily declines and decays; and the same law of limited duration doubtless extends to a large proportion of such tissues as are actively concerned in the maintenance of the organic functions; as for example, the Corpuscles of the blood, the Epithelial cells of many glands which are instrumental in the process of Secretion, the cells forming the parenchyma of the Absorbent and Vascular Glands, and many others.

II. The contrary extreme to this may be found in those tissues whose functions are rather *physical* than vital; and especially in such as undergo consolidation by the deposit of solidifying matter, either in combination with the animal membrane or fibre, or in its interstices. Such tissues are more withdrawn from the general current of vital action; and there seems to be no definite limit to the duration of some of them, except such as is imposed by the chemical and mechanical degradation to which they may be subjected. This appears to be the case with the simple Fibrous tissues, especially the yellow, even in their soft or unconsolidated state; but it is far more obvious in the dentine and enamel of Teeth, which are formed by the combination of calcareous salts with an animal matrix, and which retain their condition apparently unchanged through the whole remainder of life, under circumstances which show that if any nutritive action takes place in them, its amount must be extremely small. In the dentinal structures of the young, however, there is obviously a determinate limit of existence; as is shown by the exuviation, at a certain definite epoch, of the first set of teeth, which exuviation is usually preceded by the death and partial disintegration of their texture. In Hair, Nails, and other Epidermic appendages, again, whose substance, when once it has undergone consolidation by the deposit of horny matter, may remain unchanged for centuries, we must recognize the same principle of indefinite duration, in connection with the cessation of vital activity; the chemical constitution of these textures, moreover, being such as renders them but little prone to be acted-upon by ordinary decomposing agencies. The limit of existence seems more determinate, however, in Bone; for not only do we find that, in the first development of this substance, a considerable part of the tissue originally generated by the consolidation of its osseous or cartilaginous matrix speedily disappears, and that during the whole period of growth of the shaft of a round bone, there is a continual removal of its inner and older portions, whereby t medullary cavity is progressively enlarged; but there is strong evidenc that, even after the bone has attained its full dimensions, a replacement of old Haversian systems by new is continually in progress.

III. In the case of the Muscular and Nervous tissues, however, we trace the operation of causes that differ from any of those already specified. These tissues are doubtless subject, like all others that are distinguished by their vital activity, to the law of limited duration; for we find that, when not called into use, they undergo a gradual disintegration or wasting, which is not adequately repaired by the nutritive processes. But their existence as living structures appears to be terminable at any time, by the exercise of their functional powers; for the development of muscular contractility or of nervous force seems to involve, as its necessary condition, a metamorphosis (so to speak) of the vital power which was previously exercising itself in the nutritive operations; and the materials of these tissues, now reduced to the condition of dead matter, undergo those regressive changes which speedily convert them into excrementitious products. But the very manifestation of their peculiar vital endowments determines an afflux of blood towards the parts thus called into special activity; and from this it comes to pass, that the nutrition of these textures is promoted, instead of being impaired, by the losses to which they are thus subjected; so that their constant exercise occasions an augmentation, rather than a diminution, of their substance,—a due supply of the requisite materials being always presupposed.

317. Thus it comes to pass, that during the whole period of active life, a demand for Nutrition is created by every exertion of the vital powers, but more especially by the evolution of the Nervous and Muscular forces. The production and application of these, indeed, may be considered as the great end and aim of the Human organism, so far at least as the individual is concerned; the whole apparatus of Organic life being subservient to the building-up and maintenance of the Nervo-muscular apparatus, and of those parts of the fabric (*e.g.* the bones, cartilages, fibrous textures, &c.) which it uses as its mechanical instruments. Thus the activity of all the Organic operations, when once the full measure of growth has been attained, is mainly determined by that of the Animal functions; and as the 'rate of life' of all the parts which minister to the former will be proportioned to the energy with which they are called-upon to perform their functions, their duration will diminish in the same proportion, and hence occasion will arise for their continual renewal.* But since, in the attainment of the adult con-

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* Such an excellent illustration is afforded by the phenomena of Vegetation, of the doctrines here propounded, that it scarcely appears desirable to pass it by in this place, although it has been elsewhere more fully referred-to (PRINC. OF COMP. PHYS.," §§ 265, 358).—The leaves of Plants serve, like the absorbing and assimilating cells of Animals,

dition, the productive capacity has undergone a gradual diminution, whilst the exercise of the animal powers has become vastly increased, the formative processes are only capable of *maintaining* the Organism in its state of completeness and vigour, by making-good the losses consequent upon the continual disintegration to which it is subjected by its nervo-muscular activity. And with the advance of years, the further diminution of the productive capacity involves,—on the one hand, a progressive decrease in the substance of the tissues and organs most important to life (their bulk, however, frequently remaining unchanged, or even increasing, in consequence of the accumulation of fat),—and on the other, a gradual weakening of its powers of action. See CHAP. XVIII.

318. The performance of the function of Nutrition, the demand for which arises out of the causes that have been now discussed, is dependent, not merely upon a due supply of pure and well-elaborated blood, but also upon the normal condition of the part to be nourished, and especially upon its possession of a right measure of 'formative capacity;' in virtue of which, the newly-produced tissues are generated in the likeness, as well as in the place, of those which have become effete. The exactness of this replacement is most remarkably shown in the retention of the characteristic form and structure of each separate organ or part of the body, and thus of the entire organism, through a long series of years; no changes being apparent (so long as the state of health is preserved), but such as are conformable to the general type of that alteration which the organism undergoes with the advance of life. And not only is this to be noticed in the conservation of all those distinguishing points of structure which mark the species and are essential to its well-being, but it is still more remarkably displayed in the continuous renewal of those minor peculiarities which constitute the characteristic features of the individual, and which serve to distinguish him from his fellows. And how much this depends upon the formative capacity originally derived from the germ, is evident from this, that a similar moulding (so to speak) of the nutritive material takes place, in its original development, at first into the form characteristic of the species, and afterwards into that which marks the individual; and that the peculiarities of the individual are frequently such as have been distinctive of one or other of the parents, or present a combination of both. But it is curious that the formative power should often be exercised, not only in maintaining the original type, but also in keeping-up some acquired peculiarity; as, for example, in the perpetuation of a cicatrix left after the healing of a wound. For, as Mr. Paget has remarked,

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for the introduction and elaboration of the nutritive materials which are to be applied to the extension of the fabric; the more permanent and inactive parts of which are thus generated at the expense of materials prepared by the vital operations of the more transitory and energetic. Now there is an obvious limit to the duration of the leaf-cells; but this limit is not precisely one of *time*, being rather dependent upon the *completion of their series of vital actions*. Thus, although we are accustomed to look upon the 'fall of the leaves' (which is nothing else than an exuviation consequent upon death) as a phenomenon of regular seasonal recurrence, and to regard their replacement by a new growth as occurring at a not less constant interval, yet experience shows that these intervals are entirely regulated by temperature; for if one of the ordinary deciduous trees of temperate climates be transferred to a tropical climate, it will live much faster, its leaves being shed far more frequently, and being replaced much more speedily; so that two, or even three, successive exuviations and reproductions of its foliage may take place within a year.

the tissue of a cicatrix grows and assimilates nutrient material, exactly as do its healthy neighbouring tissues; so that a scar which a child might have said to be as long as his own fore-finger, will still be as long as his fore-finger when he becomes a man. And when the mode of nutrition in any part has been altered by disease, there is frequently an obstinate tendency to the perpetuation of the same alteration; or, if the healthy action be for a time restored, there is a peculiar tendency to the renewal of the morbid process in the part; and this is stronger the more frequently it recurs, until at last it becomes inveterately established. There is, however, in the Tissues generally, as in the Blood, a general tendency to a return to the normal type, after it has undergone a temporary perversion; and thus it is that we find the typical structure of parts gradually restored, when the morbid tendency has been overcome; and that even cicatrices and indurations, notwithstanding their usual obstinate persistence, occasionally disappear. The normal type is, perhaps, less likely to be thus recovered, when the departure from it is very slight, and consists rather in the wrong plan (so to speak) on which the new matter is laid down, than in a perversion of the nutritive process itself.

2. *On the Balance of the Vital Economy, or the Relations which subsist between the Ingesta, the Metamorphosis of Tissue, and the Egesta.*[*]

319. During the last few years many laborious investigations have been undertaken, with a view to determine what may be called the "balance of the vital economy;" or in other words, to ascertain not only the kind and quality of food requisite to maintain life under varying external conditions, but to gain an insight into the manner in which different kinds of food are applied to the formation of tissue, and to the maintenance of animal heat; and also the mode in which the results of their metamorphosis within the body are ultimately discharged by the various excretory organs. The experiments of Chossat and Mr. Savory already alluded to (§ 40), may be said briefly to show that, during inanition, an animal lives upon itself, consuming about one-half of its body before death occurs; and we may be sure, from the care that we elsewhere see to be taken by nature in the preservation of life, that the animal then lives most economically. But we cannot conclude from analyses of its egesta in the fasting state, or from calculations based on those analyses of the quantity of Albumen or Fat actually consumed in the acts of life, that we have obtained accurate data of the minimum required for the maintenance of the Animal in its normal state; for numerous experiments have shown, that if the same amount of food be given to an animal as will exactly cover its egesta in the fasting state, the excretions by skin and lungs, urine and fæces, will exceed that quantity in weight; clearly showing that the animal

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[*] The following are some of the more important recent works on this subject:—Bidder and Schmidt, "Die Verdauungssäfte und der Stoffwechsel," 1852. Lawes and Gilbert, "Philosoph. Trans.," 1859. Bischoff and Voit, "Die Gesetze der Ernährung des Fleischfressers," Leipzig, 1860. Henneberg and Stohmann, "Beiträge zur Rat. Futterung der Wiederkauer," Braunschweig, 1860. Ranke, "Archiv f. Anat. und Phys.," 1862. Pettenkofer and Voit, "Annal. d. Chemie und Pharmacie," 1862. Schützenberger, "Chemie appliqué à la Physiologie," 1864.—The Editor must here acknowledge his obligations to the standard works of Funke, Ludwig, Vierordt, Budge, Longet, and Milne-Edwards; in each of which, excellent sections on "Nutrition" will be found.

still consumes a portion of its own body, or, in other words, that more than a minimum is required. According to Bidder and Schmidt, whilst the loss of weight sustained by an inanitiated Carnivorous quadruped is about 2·2 per cent daily, nearly twice as much, or 4·4 per cent, is required to keep up its weight to the ordinary standard. The cause of the increased 'change of matter' which occurs when a due supply of food is consumed, has probably been correctly referred by these experimenters to the circumstance that the performance of the various operations of digestion, assimilation, &c., which are necessary preliminaries to the appropriation of nutritive matter by the tissues, itself involves no inconsiderable consumption of what was previously existing in the body. Hence they estimate that the respective amounts of the various digestive fluids which are daily poured into the alimentary canal of an adult Man weighing 14 stone, are nearly as follows:—

	oz.		grains.	
Saliva	56·8	containing	233	of solid matter.
Bile.	56·8	,,	1208	,,
Gastric juice . . .	147·2	,,	2976	,,
Pancreatic fluid . .	7·1	,,	310	,,
Intestinal juice . .	7·1	,,	46	,,

So that nearly 10 oz. (*troy*) of solid matter are separated from the blood in the digestive secretions, for the purpose of introducing new alimentary materials of not more than two or three times the amount; and thus we see that a large portion of the food ingested and assimilated must be consumed in providing for the introduction of a further supply, in addition to that which, when duly assimilated, is applied by the nutritive processes to the repair of the solid tissues.

320. The mode of conducting experiments of this nature consists, in the first place, in administering to an animal definite quantities of aliment, the chemical composition of which is accurately known; the quantities and composition of the several excreta are then ascertained; and finally, the variations in the total weight of the body from day to day are determined with the most rigorous exactitude. It is then obvious that we shall be able to ascertain approximatively the amount of Oxygen absorbed, and the ultimate, and to some extent even the intermediate changes which the constituents of the food have undergone. The real difficulty in these inquiries lies not only in the precise estimation of the nature and quantity of the various excretions,—a difficulty which is experienced to some extent when the products of only a single excretory organ are under examination, and which is increased manyfold in attempts to determine the variations of all—but in referring the organic compounds found in those egesta to their true origin from the constituents of the Food, or of the tissues which have undergone metamorphosis in the body. Admitting, then, that in such calculations as those which will now be adduced, various elements of error are present, which only frequent and careful subsequent experiments can wholly eliminate, it will be found that the precision of modern research has obtained results of surprising accuracy; giving indications that it will hereafter be possible to follow closely every step of the successive changes which the different kinds of food undergo, from the moment of their introduction into the body, to the period of their ultimate discharge. Before proceeding to

consider the effects of variations in the quantity and kind of food upon nutrition generally, the following Tables, drawn up by Vierordt, may be advantageously studied. They represent the Ingesta and Egesta of a well-nourished Man for a single day, the quantities being expressed in grains.

INGESTA.

	Total.	HO	C	H	N	O	O of Air.
Air	11,488	—	—	—	—	—	11,488
Albumen . . .	1,852	—	990	133	292	438	—
Fat	1,390	—	1,083	158	—	147	—
Starch	5,095	2,828	2,267	—	—	—	—
Water	40,684	—	—	—	—	—	—
Salts	494	—	—	—	—	—	—
	49,515						
	11,488						
	61,003	2,828	4,392	291	292	585	11,488
						12,073	

EGESTA.

	Total.	HO	C	H	N	O	Salts.
Lungs	18,990	5,095	3,841	—	?	10,054	—
Skin	10,342	10,190	40	—	—	111	—
Urine	27,267	26,248	105	35·5	244	140	401
			46	15·5	—	31	
Fæces	2,656	1,976	309	46·	46	185	93
Total	—	43,509	4,341	97	290	10,521	494
Water formed. .	1,746						
				194		228	
	61,001					1,324	
				291			
						12,073	

In the second Table (Egesta) it will be observed there are two series of numbers under the head of Urine. The upper one denotes the quantity of Urea and other nitrogenous compounds; the lower, that of the remaining organic constituents of the Urine. The number 10,054, under the head of Oxygen, also indicates the quantity of that gas contained in the Carbonic Acid eliminated by the Lungs. As regards the Hydrogen of the Egesta, it will be observed that one-third is already in combination with oxygen; there remain, therefore, two-thirds (194 grains) to be oxidized in their passage through the body. These require 1552 grains of oxygen, and of this the greater part (1324 grains) is derived from the atmosphere, the remaining 228 grains being derived from the food itself, which last is that quantity of oxygen which is not covered by the other excreta.—The relative proportions in which the Egesta are distributed amongst the several excretory organs appear to be, therefore, the following:—

The Lungs	eliminate	32	per cent of the total excreta.
The Skin	,,	17	,, ,,
The Fæces	,,	4½	,, ,,
The Urine	,,	46½	,, ,,

—In now endeavouring to trace some of the metamorphoses which the food undergoes in its passage through the body, it will be convenient to consider the evidence which can be obtained by an analysis of the excreta, of the nature and quantity of the constituents of the body which undergo metamorphosis during inanition—that is, during the absence of all food except the oxygen inspired by the Lungs. The protracted and careful experiment instituted by Bidder and Schmidt on a Cat will here be recorded, and thus the mode of proceeding in these inquiries will be indicated; and it will afterwards be sufficient to mention the general conclusions obtained from other experiments made with the view of determining the influence of special kinds of diet.

321. Bidder and Schmidt found that a Cat deprived of Food died in 18 days, having lost half its weight. During this interval they observed that the diminution of weight which took place was equal for equal periods, excepting during the first few days, when it was somewhat greater in consequence of the excretion of the remains of the previous food. The several excretions also diminished, though by no means in exact proportion to the loss of weight of the body generally: the quantity of Carbonic acid expired, for instance, though at first steadily falling with the diminishing weight of the body (so that during this period a given weight of the animal constantly evolved the same weight of that gas), increased from the 8th to the 16th day (so that a given weight of the body eliminated a constantly increasing quantity), whilst during the last two days it became rapidly less, a change which was coincident with the rapid fall of temperature observed by Chossat to occur shortly before death.* The quantity of Urine, again, at first fell proportionately more rapidly than the weight of the body; from the 3rd to the 16th day it sank proportionately, and during the last two days far more rapidly than the general weight of the body. After the 10th day all the Bile secreted was discharged by the Fæces. The proportions of Sulphuric and Phosphoric Acids increased absolutely, but their relative proportions remained unchanged. It is remarkable, as showing the great importance of Chloride of Sodium in the animal economy, and the tenacity with which it is retained by the tissues, that this salt soon entirely ceased to be excreted. It was found that the whole amount of Nitrogen excreted by the Urine and Fæces in the 18 days was 475 grains. Now the proportion of Nitrogen in the muscles of the Cat, *deprived of water*, was 15·07 per cent; and this might also be considered as representing the proportion of Nitrogen in the albuminous compounds contained in the Blood and in the nervous and glandular tissues, which are expressly included by Schmidt as furnishing a portion of the excreted Nitrogen. Consequently 475 grains of Nitrogen would correspond to the metamorphosis of 3156 grains of Albumen. But every 3156 grains of Albumen contain 1578 grains of Carbon; and if this amount be deducted from the total quantity of Carbon excreted during the 18 days by the lungs, kidneys and bowels,

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* In Pettenkofer and Voit's experiments the quantity of Carbonic Acid was found to fall at the close of life to one-half of its previous amount.

which amounted to 3180 grains, there is a remainder of 1602 grains of Carbon excreted by those organs, which must clearly have proceeded from the metamorphosis of some other tissues than the albuminous. They must proceed from the disintegration of Fat. But 1602 grains of Carbon represent 2050 grains of the ordinary fat of the Cat: that quantity must, therefore, have been decomposed during the period of inanition. In this manner, then, the proportions of albumen and of fat which underwent metamorphosis during the 18 days are obtained. If these be together deducted from the total loss of weight experienced by the animal, 18,543 grains, we obtain the number 13,337 grains, which represents the loss of water by the various excretory organs. A certain proportion of this water, which is calculated by Schmidt to amount to 10,906 grains, proceeds from the water of hydration of the decomposed albumen of the Blood, Muscles, Nerves, &c., and the remainder is drawn from the other constituents of the body. To render these results more intelligible, Schmidt has constructed the following table:—

Material undergoing Metamorphosis, in grains.	Water.	Carbon.	Hydrogen.	Nitrogen.	Oxygen.	Inorganic substances.	Sulphur.	Phosphoric Acid.	Hair, Mucus, Phosphates, and Fat in Fæces.
3156 grains of dry Albumen .	—	1,578·5	207·3	475·7	676·4	185	33·55	58	—
2050 grains of Fat	—	1,601·5	240·7	—	207·6	—	—	—	—
13,337 grains of Water . . .	13,337	—	—	—	—	—	—	—	—
2030 grains of Water were also drank . .	2,030	—	—	—	—	—	—	—	—
Total, *exclusive* of Oxygen absorbed by the Lungs . . .	15,367	3,180	448	475·7	884	185	33·55	58	—
There were excreted by the Lungs, Kidneys, and Fæces, *exclusive* of the expired Water, and of the Oxygen combined with Carbon (as CO_2), and with Sulphur (as SO_3) . . .	11,341	3,180	72	475·7	284	154·8	17·4	55	190
Aqueous Vapour expired . .	4026	—	376	—	600	—	—	—	—

From these data the quantity of Oxygen absorbed by the animal in 18 days may be calculated, by deducting from the absolute quantity of Oxygen expired in combination with Carbon and Hydrogen, the amount of

Oxygen (= 600 grains) remaining disposable from the metamorphosed constituents of the body (albumen and fat). Schmidt thus calculates that 9336 grains were absorbed by the Lungs, of which 76·5 parts reappeared, combined with carbon as carbonic acid, in the expired air.—The metamorphosis of tissue having been determined in this way for the whole period of 18 days, and the amounts of the several excreta having been thus referred to their origin, we now proceed to inquire into the proportionate amounts of the different tissues undergoing this self-consumption during the several days of fasting; since, from the variation which has been already mentioned as occurring in the nature and quantities of the excreta, it is evident that the consumption of the animal's own tissues, and the disintegration and discharge of their products by the several excretory organs, do not remain the same. The most important of the conclusions drawn by Schmidt on this point are—1. That whilst the daily quantity of Fat undergoing oxidation, in a fasting animal, remains nearly constant; that of the Albumen falls in the course of the first two days to one-half, then remains constant for eight days, then falls slowly, and during the last two days diminishes rapidly and considerably. The exhaled carbonic acid amounts at first to double, and at the close of life to three times the amount of the constituents of the body decomposed,—a necessary consequence of the circumstance that at the former period (as is shown by the amount of urea eliminated in the urine) the albuminous compounds, but at the latter the fatty substances, are chiefly metamorphosed. 2. The quantity of expired aqueous vapour diminishes continually but unequally, falling more quickly at the commencement and at the end of the experiment. The proportion of aqueous vapour eliminated by the skin and lungs to that discharged by the urine and fæces remains constant as 10 : 7. The absorption of oxygen was also found to diminish unequally, being much less at the commencement of the period of inanition and towards the close of life. The quantity of oxygen expired as carbonic acid also fell (from 80 to 73 per cent). On the whole, a fasting animal loses daily 1 per cent of its body substance, calculated *as free from water*, of which 0·6 is albuminous and 0·4 fat; and as terminal products of these substances, plus the oxygen inspired, and *including* the water normally present, there are discharged—

2·16	per cent of the body weight of	Carbonic acid	By the Skin and Lungs.
1·60	,, ,,	Aqueous vapour	
0·20	,, ,,	Urea	By the Kidneys.
0·008	,, ,,	Sulphuric acid	
0·011	,, ,,	Phosphoric acid	
0·029	,, ,,	Salts	
0·08	,, ,,	Dry Fæces, including 0·62 per cent of biliary matters	
2·24	,, ,,	Water	By the Urine and Fæces.

Bischoff and Voit have made several similar series of researches on a dog, after having previously in one experiment fed him well; in a second, after having gradually diminished the amount of food; and in others, after having given him an excessive supply of meat and fat. The general conclusions at which they arrived were, that during inanition the amount of consumption of the animal's own tissue was dependent upon its size; since, if it had been previously well fed, it lost more in a given time, and if it had been badly fed, it lost less; living in the latter case, as it were, more economically. And further, the consumption was found to fluctuate between the two chief factors of the body, the muscular tissue and the fat, in such a manner that a very muscular animal consumed more flesh, and a very fat animal more fat; which result is attributable in part to the presence of a greater bulk or mass of the tissue, which is consequently more exposed to the action of the oxygen absorbed, and undergoes a greater amount of disintegration. In the experiment in which the animal had been previously well fed, and with a mean weight of 70 lbs., the proportion of nitrogen to that of carbon eliminated was as 1 : 19; the proportion of nitrogen eliminated per diem for each 1 lb. of body weight being 2·1 grains, and of carbon 40 grains. In a second experiment, where the dog had previously been fed on progressively-diminishing quantities of meat, and weighed 70·7 lbs., the proportion of N. to C. was as 1 : 24, and there were eliminated for each 1 lb. of body weight 1·68 grains of N. and 40 grains of C. In a third experiment, where the dog had been so abundantly fed that its mean weight throughout the experiment was 85 lbs., the proportion of N. to C. was as 1 : 16·3, the quantity of N. eliminated per diem to each 1 lb. of body weight being 1·54 grains, and 25·2 grains of C.—Similar observations have been made by Ranke* on himself; and the influence of diet in Man, in effecting a variation in the composition of the excretions, is well shown in the following table, based on his experiments:—

	Proportion of Nitrogen to Carbon in the collective excretions of the Skin, Lungs, and Kidneys.	Quantity of Nitrogen excreted per diem for each 1 lb. of body weight, in grains.	Quantity of Carbon excreted per diem for each 1 lb. of body weight, in grains.
With mixed food	1 : 12	1·817	45·7
In inanition	1 : 17	1·000	17·82
With non-nitrogenous food	1 : 25	·788	19·5
With excessive and exclusive meat-diet (4 lbs)	1 : 6	8·67	52·8

Ranke found in his experiments that Man required more carbon, *i.e.* more fat or starch, in his food to supply the wants of his economy, than appeared to be requisite in the Dog experimented on by Bischoff and Voit; and he further remarks that the quantity of nitrogen appearing in the excreta bears an inverse proportion to the carbon contained in the food: consequently, when the fat or starchy constituents of the food are insufficient, the albuminous constituents of the body are drawn upon or are consumed to maintain the temperature. Moreover, he believes that he has proved that, after a few days of fluctuation consequent upon change of diet, the whole amount of nitrogen ingested in the food may be recovered from the urine and fæces. He found also—1. That the minimum quantity of urea (containing nearly all the nitrogen) is discharged during hunger. 2. That whilst mere increase in the quantity of food, irrespective of its composition, has no effect in increasing the quantity of nitrogen eliminated by the kidneys, an increase in the proportion of nitrogenous diet is followed by an increased discharge of urea, though this does not rise proportionately for 24 hours at least; the effect, however, enduring for some time after the withdrawal of such food. 3. The same holds with regard to uric acid.—In none of the experiments performed by Bischoff and Voit was any direct estimate made of the Carbonic Acid evolved at the Lungs; but it was calculated on Regnault's and Reiset's average for dogs, derived from their experiments, and no allowance was made for the diminution which, as has already been observed, takes place in the respiratory activity of fasting animals during the last day or two previous to death, and was distinctly stated to occur by Schmidt. This omission seems to be of considerable importance, however, since it has been recently established by Pettenkofer and Voit, in experiments made upon the same Dog as that employed by Bischoff and Voit, that the quantity of Carbonic acid varies not only within very considerable limits, but that it bears no definite relation to that of the Nitrogen discharged. In their experiments, whilst the quantities of nitrogen eliminated as urea varied under different circumstances as 1 : 13, that of carbonic acid only varied as 1 : 2·7.

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* "Müller's Archiv," 1862, p. 335 *et seq.*

322. The conclusions arrived at by Bischoff and Voit upon the effect of feeding their Dog on pure meat-diet are especially interesting. They found that in order that the animal should neither lose nor gain in weight, a daily supply of meat equal to from 1-20th to 1-25th of the whole weight of its body was required (a much smaller proportion than that found requisite by Bidder and Schmidt in the experiments on the Cat); and that if less than this were supplied, a loss of weight took place in consequence of the animal consuming some of its own flesh and fat; whilst if more than this proportion were supplied, a gain in weight occurred. But to produce a daily increase in weight—a constantly increasing weight—a relatively larger proportion of food was continually required, until at last a maximum was attained; the animal then loathed its food, consumed no more, and rapidly returned to its standard weight. At the same time they found that the quantity of meat which the dog required to cover loss on the one hand, and to form flesh on the other, varied always with the mass of the body. In the well-fed animal, therefore, it required more, in the badly-fed less, to produce the same effect. They further conclude that when large quantities of meat are consumed, the products of its retrogressive metamorphosis take up or combine with the oxygen of the blood, and that thus the fat of the animal is spared; the animal's temperature being sufficiently maintained by the combustion of the secondary products of the disintegration of the albuminous compounds.

323. The results of the addition of fat to the food of a carnivorous animal also possess a high degree of interest. Bischoff and Voit found that in inanition about 3860 grains of muscular tissue underwent metamorphosis in their dog per diem, as indicated by the quantity of nitrogen in the urine; whilst when from ½ to ¾ lb. of fat was daily given, the quantity of nitrogen eliminated only indicated a metamorphosis of 3134 grains of the albuminous constituents of the body. In like manner it was found that if the animal were placed on a diet of meat so sparing as to be insufficient to maintain it at its full weight, and therefore to necessitate the consumption by the animal of its own body, the addition of fat to the food immediately diminished the quantity of its own body-flesh consumed; and yet again, if fat were freely given, a much less quantity of meat was required to maintain the animal at its full weight, than if it

were fed on meat alone. From all these experiments it is clear that, as Bischoff and Voit conclude, the fat exerts a protective influence over the albuminous tissues, sparing their consumption or oxidation by its own greater affinity for oxygen; so that, whereas during inanition, insufficient meat-diet, or sufficient diet of meat free from fat, the heat of the animal is maintained at the expense of the oxidation of the albuminous tissues, and the products of their retrogressive metamorphosis,—when fat is added to the food, its direct combustion takes up the oxygen, and prevents its action on the nitrogenous tissues. It even spares its action on the animal's own fat; since this, being stored up in vesicles, is less accessible to the action of oxygen than the free fat contained in the blood. Moreover, it appeared that if increased quantities of meat were supplied with the addition of abundance of fat, an increase in the quantity of nitrogen was observed, just as when increased proportions of pure fat free from flesh were administered. From this Bischoff and Voit conclude that the fat, besides sparing the tissues, exerts a second influence, that of aiding their metamorphosis; and that the products of the metamorphosis of these albuminous constituents, after having formed tissue, accumulating in the blood, take up the oxygen, even though the fat be also present. A much simpler explanation, however, appears to be, that in these experiments, after the condition of equilibrium between the food supplied and the requirements of the tissues had been attained, the extra or surplus albuminous compounds undergo direct oxidation in the blood; and thus, together with the fat, minister to the maintenance of the temperature of the animal, whilst their nitrogen is discharged as urea.* Whilst, therefore, a certain proportion of fat in the food diminishes the quantity of nitrogenous diet required, we can readily understand that in order to fatten an animal a certain and indeed a large proportion of albuminous material, together with fat, must be supplied in the food; for not only is such nitrogenous material requisite for the maintenance of the cardiac, respiratory, and other movements, but the products of its retrogressive metamorphosis, by combining with oxygen, spare the fat of the food and of the tissues, and enable the former to be deposited in the body. And this view is corroborated by the observation of Pettenkofer and Voit, that if a large quantity of meat were taken, the entire quantity of carbon contained in it was not found in the expired air; but on the other hand, the whole amount of nitrogen re-appeared in the urine, whence it seems probable that fat was deposited.* Sugar and starch consumed with a meat-diet seem to operate in precisely the same manner as fat, except that their action, in combining with oxygen, and thus sparing both the adipose and nitrogenous tissues, is, in consequence of their greater affinity for oxygen, still more marked than fat; and if large quantities of sugar be given with sufficient albumen, a deposition of fat invariably takes place.

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* It is important here to notice that Bischoff and Voit assume that all the Nitrogen of the absorbed food is directly applied to the formation of tissue, and, indeed, of muscular tissue; secondly, that all the nitrogen excreted proceeds from the metamorphosis of muscular tissue; and thirdly, that nearly the whole of the nitrogen proceeding from such disintegrated muscle is discharged by the kidneys as Urea; a certain small proportion, bearing a definite ratio to the body-weight, and independent of the quantity of the food, being eliminated by other organs, as perhaps by the Skin and Lungs, under the form of Carbonate of Ammonia. But it is well known that, independently of the nervous and glandular tissues containing nitrogen as an essential constituent, and therefore eliminating it during the disintegration consequent on their vital activity, a certain proportion of nitrogen is discharged by the skin through the desquamation of epithelial scales and the growth of hair, &c.; whilst even in the urine itself, besides the urea, various other compounds containing nitrogen are present. Now, although the contingent of each of these is small, yet in the aggregate they may, and in many instances probably do, amount to a considerable quantity; and thus it happens that some experimenters have found a remarkable deficiency in the amount of nitrogen excreted, as compared with that which had been ingested, when the urea alone has been taken into account. Thus Lehmann, on a purely animal diet (eggs), only recovered 4-5ths of the nitrogen from his urine; and Schmidt found a deficiency of nearly one-half in some of his experiments. Hoppe has also shown that an extraordinarily different amount of nitrogen is recoverable from the urine, according to the nature of the food: when this was purely animal, nearly 5-6ths of the nitrogen was eliminated by the urine; but when a large quantity of sugar was administered with the same quantity of meat, very little more than one-half of the nitrogen could be recovered.

324. The differences which exist between Carnivora and Herbivora, in regard to the mode in which the constituents of the Ingesta are distributed through the excretions, is well shown in the following table, which represents the estimate deduced by Bidder and Schmidt from their observations upon a full-grown Cat, which was allowed for a week as much meat as it could eat, and the results obtained by Valentin from the observations of Boussingault upon a Horse.

Of 100 parts of	Fæces.		Urine.		Pulmonary and Cutaneous Exhalation.	
	Cat.	Horse.	Cat.	Horse.	Cat.	Horse.
	per cent.	per cent	per cent.	per cent.	per cent.	per cent.
Water	1·2	61 8	82·9	5·9	15·9	32·3
Carbon	1·2	34·6	9·5	2·7	89·4	62·7
Hydrogen	1·1	40·3	23·2	2·5	75·6	57·2
Nitrogen	0 2	55·7	99·1	27·1	0·7	17·2
Oxygen	0·2	41 4	4·1	1·0	95·7	57·6
Ashes.	92·9	85·5	7·1	16·2	—	—
Sulphur	50·0		50·0		—	—

The first and most remarkable feature of difference between these two sets of results, is the very large proportion which the fæcal discharges of the Horse bear to the other excretions; this obviously proceeds from the indigestibility of a large part of the alimentary substances it consumes. Of the *water* taken into the alimentary canal or formed within the body, nearly two-thirds passes-off with the fæces in the Horse, whilst nearly the whole is absorbed in the Cat: and of that which is absorbed by the Horse, little more than one-seventh passes into the urine, the remainder being exhaled from the lungs and skin; whilst in the Cat, the proportion which passes-off by the skin is less than one-sixth of that which is absorbed, the remainder being eliminated by the urine. Of the *carbon* taken into the system, a relatively-larger proportion passes-off by the lungs in the Horse, while a relatively-larger proportion enters the urine in the Cat: this is probably because the great bulk of the carbon in the food of the Horse exists in those non-azotized compounds, which can be readily converted by oxygenation into carbonic acid and water, and which consequently yield little or nothing to the urine; whilst those products of the decomposition of albuminous substances which pass into the urine, though especially rich in nitrogen, carry with them a certain measure of carbon into that excretion. It is probably for the same reason that the amount of *hydrogen* is relatively larger in the pulmonary exhalation of the Horse, and in the urinary excretion of the Cat. On the other hand, we see that whilst the *nitrogen* of the food is almost exclusively eliminated through the urine in the Cat, as much as 40 per cent of that which has been absorbed into the system passes-off by the lungs and skin in the Horse. Nearly the whole of the *oxygen*, in each case, passes-off by the lungs; the relatively-larger proportion in the urine of the Cat being due to the greater amount of those products of decomposition of albuminous substances into which oxygen enters. That half of the *sulphur* contained in the food of Carnivora should pass off in the fæces in an unoxidized or imperfectly-oxidized state, and that the other half should be excreted, chiefly in the condition of sulphates, formed by the oxidation of the sulphur and by its combination with alkaline bases, is a fact of great interest, in connection with the question of the ultimate destination of the bile. For, with the exception of the small amount of sulphur contained in the undigested residue of the food, the sulphur of the fæces must be entirely derived from the bile, of which secretion it is an important constituent. But of the bile which is poured into the alimentary canal, a large part is certainly re-absorbed (§ 103), its constituents being destined to undergo oxidation, and to be eliminated, for the most part, by the respiratory process; and it is probably from this re-absorbed portion of the bile, that the sulphur of the urine is derived. It appeared from other experiments performed by Bidder and Schmidt, that, when the bile was not allowed to flow into the intestinal tube, but was collected from biliary fistulæ, from 10 to 12 per cent of the absorbed carbon, and from 11 to 13 per cent of the absorbed hydrogen, passes into the biliary excretion: neither the solids of the fæces, however, nor those of the urine, were sensibly affected by the abnormal removal of these constituents, which fell entirely upon the products of respiration, these being diminished to that amount. Hence it seems obvious, that although only half of the *sulphur* is taken-up again, nearly the whole of the *hydrocarbonaceous* part of the bile must be re-absorbed, to be finally eliminated by the respiratory process; so that we may consider the entire of these constituents absorbed from the food, that remains after the separation of the components of the urine, as being finally separated from the body by the respiratory process. According to Bidder and Schmidt, 100 parts of dry flesh are decomposed in the living body, with the co-operation of 167 parts of oxygen obtained from the atmosphere, into 31 parts of urinary substances, 2 parts of fæcal matter, 182 parts of carbonic acid, and 52 parts of aqueous vapour. Nearly the same relative proportions are presented when the waste of tissues is not supplied by new alimentary matter, as exist when the animal is kept on a flesh-diet; so that we may regard these as representing the destination alike of the products of the ultimate metamorphosis of the tissues of the living body, and that of the products of decomposition of superfluous or unassimilated aliment of the Carnivorous animal. In the Herbivorous animal, on the other hand, only a small part of whose aliment is albuminous in its composition, the proportion just stated will apply only to that part, and to the products of the ultimate metamorphosis of its tissues; since the whole of the hydrocarbonaceous components of its food, whether saccharine or oleaginous, are eliminated by the pulmonary and cutaneous exhalation. Thus, then, we see that, throughout life, a continuous interchange of material takes place in the very substance of the tissues, and that new material, derived from without, is being constantly laid down to replace the old and effete substance, which, in the act of developing force in one form or another, undergoes oxidation, and, as we shall immediately see (§ 327), is then taken up by the circulating current, to be removed by the excretory organs. In the earliest periods of life, how active soever the oxidizing processes may be, the power of the fabric to seize and apply the substances employed as food is superior, and the results are seen in the processes of growth and development. In adult life the balance is more equably preserved, and all the faculties of the body attain their highest state of efficiency. But in old age, with the increasing debility of all the vegetable processes, with diminished capability of absorption, diminished energy and rapidity of the circulating current, with more compact and drier tissues there comes to be a gradual deficiency in the processes of nutrition, until at length the body ceases to be able to nourish itself, the waste is greater than the supply, and the death of extreme old age may be justly compared, in the wasting oftentimes preceded by the degeneration of the tissues and the gradual failure of the temperature, to death by inanition.

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* See Syd. Soc. "Year-Book," 1862, p. 28.

325. Of all the constituents of the body, none are of more complex chemical composition, and undergo more numerous and varied changes, than Albumen.* The relations which this substance bears to the living body are of the most important and fundamental character; since, as elsewhere shown, it is the original *pabulum* at the expense of which all the solid tissues are generated, whilst it also affords the material for the production of the fibrin, the globulin, and the hæmatin of the Blood. It appears, however, to be itself entirely destitute of formative capacity; for in no exudation which is purely serous do we ever trace the slightest indication of organization; and its conversion into the various kinds of tissue, therefore, must be entirely due to their own power of appropriating and transforming it. The great function of the Albumen of the blood, then, is to supply the material for these various transformations; and we accordingly find that whatever other changes the fluid may undergo, whether it loses its fibrin or its red corpuscles, or both, albumen is still present in abundance. Its ultimate source is to be found in the food; but the serous liquid which percolates the tissues of the body may be regarded as a reserve-store, to be drawn-upon in case of need, furnishing albumen to the blood when it might otherwise be deficient; and thus perhaps it is, that abstinence or repeated losses of blood do not produce the degree of depression in the proportion of albumen, which might be expected from the very marked reduction they effect in that of the corpuscles. When an excess of Albuminous matter is ingested as food, the injurious effects which might follow the too great augmentation of this constituent of the Blood, appear to be averted by the readiness with which it undergoes *retrograde* as well as *progressive* metamorphosis; for, if not speedily subjected to the latter change, it appears to be affected

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* The formula given for it by v. Gorup-Besanez being $C_{216} H_{169} N_{27} S_{3} O_{68}$.

by decomposing agencies, and to be eliminated from the system by the excretory apparatus, under the form of urinary and biliary matter.

326. *Disintegration of Albumen.—Origin of Urea and Uric Acid.*—From various considerations it would appear that the albuminous compounds in their retrograde metamorphoses are capable of breaking-up into two groups of substances, of which one contains the whole of the nitrogen, whilst the other is composed of carbon, hydrogen, and oxygen alone. The former are ultimately eliminated from the body as urea or some analogous compound; the latter are discharged in the form of carbonic acid and water. Of the former series, we know that whilst Leucin ($C_{12} H_{13} NO_4$), Tyrosine ($C_{18} H_{11} NO_6$), and Glycine ($C_4 H_5 NO_4$), can be artificially formed by the action of alkalies or acids upon albumen, or even appear during its spontaneous decomposition; these same substances can also be obtained from various tissues of the body, and are always most abundant in those organs in which interstitial changes are most active, as in the spleen and liver.* From muscular tissue, again, Inosinic Acid ($C_{10} H_6 N_2 O_{10}$), Creatine ($C_8 H_9 N_3 O_4$), and the urinary constituent Creatinine ($C_8 H_7 N_3 O 2$), can be directly obtained. The relation of Inosinic Acid to Uric Acid and Urea is very intimate; whilst as regards Creatine, the recent researches of Sarokow† indicate that during active muscular exertion it is converted into Creatinine, or at all events that, in muscles exhausted by action, a greatly-increased proportion of Creatinine is generated; and it is well known that both of them are readily convertible by chemical agents into Urea.‡

327. The interesting and important question of the origin of Urea has been the subject of much recent controversy, and may here be appropriately considered. Two views have been entertained, and the partisans of each have numbered some of the most distinguished Chemists and Physiologists of the present day. According to one view, Urea is to be considered as the result of the disintegration or waste of nitrogenous tissues alone; and since the muscles contain the greatest part of the nitrogen existing in the body, and urea contains far the greater proportion of all the nitrogen excreted, it follows that the quantity of Urea eliminated ought to be a tolerably accurate measure of the metamorphosis of muscular tissue. In support of this view may be urged the fact, that if an animal be starved to death, urea continues to appear even to the last hour, the nitrogenous tissues at the same time gradually diminishing in weight. But a starving animal, as already shown (§ 58), is an animal feeding upon animal diet, for it is living upon itself; and it is therefore reasonable to suppose that all, or nearly all, the albumen of the blood is applied to the maintenance and nutrition of tissue, which, after undergoing several intermediate changes, is ultimately discharged from the system in the form of Urea. Bischoff and Voit found that a dog fed on from 23,160 to 27,792 grains of meat per diem, eliminated more nitrogen, in the form of urea, than was contained in its food; whence they conclude that the food was not only wholly applied to the nutrition of the tissues, but that a portion

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* Glycine has not, indeed, been obtained in the separate state, but it enters into the composition of the glycocholic acid of the bile. The further decomposition of leucin in the laboratory by fermentation and oxidizing agents, yields the volatile fatty acids and ammonia well known to occur in glandular organs and in the blood.

† "Virchow's Archiv," 1863, p. 544. ‡ Fownes' "Chemistry," 1861, p. 670.

of the body itself must have been used for the performance of the work constantly going on in the economy, as the movements of the heart, respiration, &c. With 27,792 grains of meat, the amount of nitrogen in the urea discharged equalled that of the food, and the weight of the animal remained stationary; it had thus no occasion to use any of its own tissue. Lastly, if the animal consumed 30,880—38,660 grains in 24 hours, there was increase of weight in the body, and *subsequent* increase in the quantity of urea; simply, according to Bischoff, because there was then an increased mass of the body from which it might proceed: the animal being at the same time capable of greater exertion, whilst the expenditure of internal force, such as that required to drive the increased mass of blood, &c., was proportionably increased. Again, facts in Pathology seem at first sight to support this view; for it has been shown that the amount of urea excreted daily is usually, though not constantly, increased in febrile diseases; and when it is borne in mind that comparatively little food is taken under such circumstances and little exertion made, the increase must be wholly attributed to the account of the more rapid wasting of the tissues. Thus Vogel and Warnecke found that in a case of typhoid fever, no less than 1065½ grains of urea were excreted daily, or nearly double the usual average, and in a case of pyæmia the extraordinary quantity of 1235½ grains. When the fever is over, the quantity of urea falls below the normal amount, in spite of the augmented quantity of nitrogenous food ingested, which is doubtless appropriated to the repair of the wasted tissues; and it then, after perfect recovery, returns to the physiological standard.—Strong as these arguments appear to be, a second view, which was advanced in this work many years ago, has of late been steadily gaining ground; namely, that the amount of Urea in the Urine can only be regarded as a measure of the metamorphosis of tissue when no more food is ingested than is required to compensate for that metamorphosis; any histogenetic matter which escapes assimilation through not being required in the system, being normally decomposed (constituting the so-called 'Luxus consumption' of recent German writers), and its azotized portion being eliminated through this channel. Many facts seem to show that this is a correct expression of the mode of origin of urea. Thus we may account for the immediate increase in the amount of urea after the employment of nitrogenous food (as shown in Dr. Edward Smith's experiments, see chap. on Urine), and for the results obtained by Lehmann, that the quantity excreted daily, when no azotized matters were consumed, and when the excretion was simply a measure of the metamorphosis of tissue, was not above half that excreted upon an ordinary mixed diet, and only 2-7ths of that which was passed when the diet was purely animal. Again, Voit found that after a full meal of meat and eggs, the quantity of urea rose till the 7th hour, and was even greater at the 16th hour than before the meal. It would certainly here seem more probable that some of the albuminous matters were directly decomposed in the blood, than that they were applied to the nutrition of the nitrogenous tissues, causing the discharge of so large a quantity of old tissue as urea. Moreover, Messrs. Gilbert and Lawes* have shown that in fattening pigs, by far the larger proportion of nitrogen consumed in the fattening food passes off in the form of urea. This occurred in animals kept in a state of almost perfect rest; and hence it is reasonable to suppose that that nitrogenous food which, if the animal had been in full activity, would have supplied the waste of tissue, was in its inactive state, with its muscles in a condition of fatty degeneration, consumed in the blood, in either case urea being the terminal product. The experiments of Hammond* have further clearly shown that, although when he consumed purely-albuminous food there was a great increase in the amount of urea, there was at the same time a great diminution of his physical strength; which seems incompatible with the idea of that active metamorphosis of tissue which must be supposed to take place if we conceive the albumen to become assimilated and replace old and effete material, whilst it is perfectly intelligible if we adopt the view that the albumen underwent disintegration in the blood itself. The conclusions of Prof. Haughton† on this point, in reference to the phenomena of Diabetes, are of much interest, not only in reference to the production of urea, but also to the formation of non-nitrogenous material (sugar) from the disintegration of albumen in the blood; for he has shown it to be highly probable that at least half the sugar eliminated is derived from the direct decomposition of albuminous substances, before their application to the formation of tissue, or at all events before they are used-up in the performance of work. In support of this statement he adduces the well-established fact, that even when all starchy matters are carefully excluded from the diet, sugar still appears in the urine; further, that in diabetes there is not only an abnormal proportion of sugar in the urine, but that the quantity of *urea* is also greatly increased—a point which has been very generally overlooked; and he remarks, that very simple chemical formulæ will explain the formation of Sugar and Urea from Protein. Thus—

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* "Phil. Trans.," 1859, p. 554.

$$\begin{aligned}&1\ \text{Eq. Protein}\ (C_{36}\,H_{27}\,N_4\,O_{12}) + 3\,O + 23\,HO + 4\,CO_2\\&= 3\ \text{Glycose}\ C_{12}\,H_{14}\,O_{14} + 2\ \text{Urea}\ C_2\,H_4\,N_2\,O_2.\end{aligned}$$

Now, since the excreta from the lungs and kidneys give, in the carbonic acid and urea they contain, a measure of the amount of metamorphosis of tissue, as well as of the disintegration of albumen or surplus consumption, and since these are unusually great in diabetic patients, though such patients are in a condition of extreme torpor both of mind and body, the quantity of food which they consume being at the same time extraordinarily large; it seems a not unreasonable conclusion from these facts,—the large consumption of food, the small amount of work done, and the appearance in the excreta of the products of the simple disintegration of the albuminous constituents of the food,—that the food, from some fault in the assimilating processes, is converted not into tissue, to the construction of which it should properly proceed, but into those secondary products, Glycose and Urea, which are immediately eliminated from the system, partly by the lungs, and partly and chiefly by the kidneys. Moreover, there are some substances which, when ingested, give rise to increased excretion of urea, and yet do not seem to be themselves capable of conversion into tissue, such as Glycin, Alloxantin

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* "Experiments on Digest.," p. 27.

† "Dublin Med. Journ.," 1861, p. 272.

Thein? Uric Acid, and even Gelatin: in these instances we must suppose that the decomposition takes place in the blood itself. As regards the effects of muscular exertion, which were stated by Lehmann and Simon to increase largely the proportion of urea in the urine, and by the latter observer even to double it, it would appear from the far more extended and accurate observations of Dr. Edward Smith and Voit that this is not borne out by experiment, and that in reality even violent and prolonged muscular exertion occasions a comparatively trifling increase in the urea, though greatly increasing the excretion of carbonic acid.—There appear to be good grounds for believing that the formation of uric acid precedes that of urea. Stokvis* observed, that on warming the alkaline urates with portions of finely-divided liver, a large proportion of the acid disappears and is replaced by urea, whence he suggests that the metamorphosis ordinarily occurs in the liver. Ranke, on nearly the same grounds, argues for its formation in the spleen. Again, it has been shown by Neubauer,† not only that urea can be artificially formed from uric acid by the action of oxidizing agents, but that if uric acid be mingled with the food of rabbits, there is a great increase in the amount of urea discharged. Its composition ($C_{10}\,H_4\,N_4\,O_6$) shows a very intimate relationship with Xanthine ($C_{10}\,H_4\,N_4\,O_4$), and with Sarkin ($C_{10}\,H_4\,N_4\,O_2$); and it would thus appear to be one of the last stages of oxidation of these products of retrograde metamorphosis. From hence we may deduce the principle, which is of important practical application, that when high-feeding patients are voiding large quantities of the lithates, these may often be at once brought down by a reduction in the excess of the azotized portion of their food. Dr. Marcet found a remarkable diminution in the proportion of uric acid in the urine after violent sweating; which is in accordance with the well-known fact that Lithiasis is infrequent amongst the natives of tropical climates, though this may also be explained by their more sparing use of animal food. The effects of exercise have not been quite accurately determined. Dr. Hammond states that when at rest, on mixed diet, he eliminated daily the large proportion of 24·9 grains of uric acid; after moderate exercise 13·7 grains were discharged, and after violent exercise 8·2 grains—the urea at the same time undergoing a proportionate increase. Genth and Heller, whilst agreeing with Dr. Hammond in the diminution effected by moderate exercise, state that the quantity of uric acid again rose when the exercise was very violent; and Lehmann and Speck‡ found a slight increase after protracted exertion. This latter increase may perhaps be attributed to an insufficiency in the amount of oxygen absorbed to completely oxidize all the products of disintegration when suddenly and greatly increased. —Upon the whole, it appears the circumstances which most favour the genesis of Uric acid in the system, and the increase of its proportion in the urine if there be no obstacle to its elimination, are a highly-azotized diet and inactive habits of life; whilst the reduction of the former to what is really requisite for the due nutrition of the body, and the promotion of the respiration by moderate exercise, tend to reduce the proportion of this compound; so that under these circumstances we may almost regard it, in the language of Prof. Haughton,* as "a minute fraction of nitrogen which has escaped complete oxidation."†

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* "Donders' Archiv," 1860, p. 260. † "Liebig's Annalen," vol. xcix. p. 206.
‡ "Med.-Chir. Rev.," 1862, vol. i. p. 235.

328. Thus, besides the nitrogenous compounds into which the albuminous substances split, a series of non-nitrogenous materials probably also result from their disintegration, and these may either be of an oleaginous or of a saccharine nature. The formation of the volatile acids of fats, and of benzoin and oxalic acids, can theoretically be easily deduced from the composition of albumen;‡ and we appear to have some evidence of the generation of fat from albumen in the observations of Burdach§ upon the eggs of the Limnæus, for he found the former to increase apparently at the expense of the latter in the progress of incubation. Thus in 1000 parts of the dried ova of that animal there were—

	In the early stage.	In the late stage.
Fat	6·85	21·81
Salts	40·50	60·00
Albumen	952·65	918·19

It must also be remembered that the formation of an amyloid substance, Glycogene, is the natural function of the liver; and there is every reason for believing that this formation proceeds in great measure from the decomposition of albuminous substances, especially since it is accompanied by the simultaneous appearance of highly nitrogenous substances, such as Glycocholic and Taurocholic acids, which have been shown by Liebig‖ to be readily derivable from albumen, on the assumption of the breaking-up of albumen into gelatin (gluten) and one equivalent of Taurocholic acid, the latter containing an important element of albumen, namely, Sulphur. In conclusion, then, we may say that with regard to the albuminous, and as the experiments of Bischoff and Voit appear to prove, the gelatinous constituents of our food also, that it is probable that part go directly to the formation of tissue, and part, termed the 'Luxus consumption' by the Germans, are decomposed in the blood without forming tissue. In both instances a kind of decomposition or disintegration takes place under the influence of oxygen; by which, on the one hand, such compounds as Glycin, Leucin, Creatine, Creatinine, Guanin, Sarkin, Xanthin, Uric Acid, Urea, &c., are formed, which are, for the most part, discharged by the Urine and Fæces; and on the other, certain fatty or saccharine substances are generated, by the further combustion of which the animal heat is maintained, their ultimate products, consisting of Carbonic Acid and Water, being eliminated chiefly by the skin and lungs.

329. As regards the Fatty constituents of the body, a large proportion is undoubtedly derived from the food. Previously to absorption the members of the oleaginous group are minutely divided, reduced to the fluid

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* "Dublin Quart. Journ.," 1859, vol. ii. p. 11.

† The formation of adipocere, which was formerly much relied upon as proving the conversion of albumen into fat, appears to be owing to the combination of the fatty acids originally present in the tissue, with ammonia, lime, and potash. And again, the supposed conversion of pieces of muscle, coagulated albumen, &c., into fat, when introduced into the peritoneal cavity of animals, appears to have been disproved by Burdach, who has shown that it is simply a deposit or infiltration into the tissue, or albuminous substance introduced, and may even take place in pieces of porous wood. See Burdach, "Virchow's Archiv," 1854, band vi. p. 103; and Milne-Edwards, "Leçons," t. vii. p. 559.

‡ F. W. Burdach, "De Commut. subst. prot. in Adipem," Dissert., 1853.

§ "Familiar Letters on Chemistry."

state, emulsified, and, in part at least, decomposed by the pancreatic juice into the fatty acids and glycerine; whilst that portion which has been absorbed without decomposition appears, according to the researches of v. Gorup-Besanez, to be converted, under the influence of the active oxygen of the blood (ozone?) and the carbonated alkalies in the first instance, into the fatty acids and glycerine—the glycerine undergoing further metamorphosis into formic, propionic, and other acids. The quantity of fat contained in different parts of the body varies considerably, but it is almost universally present. The blood usually contains about 0·4 per cent, the muscles 3·3, milk 4·3, brain 8, the nerves 22, and adipose tissue 83 per cent.—The Fatty matters of the Blood are obviously destined to furnish the contents of the Adipose and Nervous vesicles; whilst their presence seems also to be required in the early stages of the production of Cells generally. One of the principal sources of their expenditure, however, is that combustive process by which the heat of the body is maintained; and the amount deposited in the tissues as fat, may be looked-upon as the surplus of the quantity ingested, that is not thus consumed. The quantity of fatty matter in the blood is liable to sudden augmentation, from the introduction of a large quantity furnished at once by the alimentary material; and this excess will continue until the surplus has been eliminated, either by the combustive, the nutritive, or the excretory operations. These last do not ordinarily remove the saponifiable fats from the body; for although the mammary secretion in the female draws off from her blood a large quantity of fatty matter, this is destined, not for its purification, but for the nutrition of her offspring; and cholesterin appears to be the only fatty substance which is normally excreted for the purpose of being removed from the body.—The question of the capability of animals to produce fat has been much disputed. There seems, however, to be no reason for doubting that it may be generated not only from the hydrocarbonaceous constituents of the food (sugar and starch), but also from the splitting-up of the albuminous compounds. The observation of Huber, that if Bees be fed upon pure sugar they will still continue to furnish wax for the comb, repeated and confirmed as it has been by Milne-Edwards* and Boussingault, and the rapid fattening of negroes which occurs at the period of cutting the sugar-canes, together with the experiments of Boussingault and those of Messrs. Lawes and Gilbert, who found† that in fattening pigs, for every 100 parts of fat in the food the animals stored up from 400 to 450 parts of fat in their bodies, seem to furnish conclusive evidence on this point. Again, the observation of Boussingault, that for animals to fatten on starchy substances a certain proportion of albumen must be present, the production of fatty acids during the disintegration of albumen, leucin, and other analogous substances, and the phenomena of fatty degeneration, all seem to point to the derivation of fat from this source also. Indeed, Messrs. Lawes and Gilbert expressly state, that whilst 2½ parts of starch must be consumed in the food to produce one part of fat, the proportion of sugar required is somewhat larger, and that of any albuminous compound somewhat smaller, to produce the same effect. The ultimate disposal of the saccharine constituents of the body, which appear to be partly derived from without, and to be partly the result of the decomposition of the albuminous constituents of the blood, as will be hereafter more fully considered (Glycogeny), is still unknown; though there seems to be every probability in favour of their being first converted into Lactic, and finally into Carbonic acid and Water.

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* Milne-Edwards, "Leçons sur la Physiologie," t. ii. p. 553.

† "Phil. Trans.," 1859, p. 543.

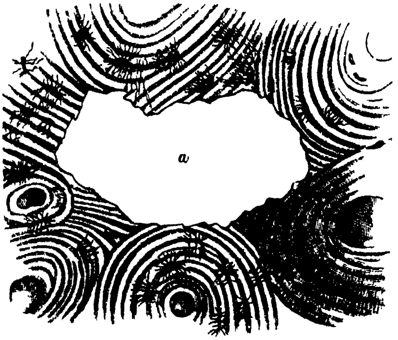
330. The uses of the various Inorganic compounds, which, as being uniformly present in the Blood, must be considered among its integral constituents, are not as yet by any means positively known; yet great advances have been recently made towards this knowledge; and it may be pretty certainly affirmed, that the presence of some of them has reference to the peculiar functions and conditions of the blood itself, whilst others are chiefly destined for appropriation by the tissues to whose growth it ministers. The former seems to be especially the case with the Alkaline salts; of which the *phosphate and carbonate of soda* would seem to have it for their chief purpose to maintain the alkalinity of the blood, on which depend not merely the liquidity of its albumen, but the facility of its passage through the capillaries, and the readiness with which its combustive materials are oxidized; whilst they also increase the absorptive power of the serum for gases. So the presence of *chloride of sodium* is needed for the conservation of the organic components of the blood in their normal condition, and it also seems to be essential to the performance of many of the metamorphic and histogenetic operations to which these substances are subjected in the economy; this salt, moreover, is itself required as a component, not only of the solid tissues generally, but also of all the secreted fluids. The *salts of potash* appear to be specially required for the nutrition of the muscular tissue; but they probably exert the same general influence with those of soda. The presence of the Earthy salts, on the other hand, would seem to have reference almost exclusively to the composition of the tissues, into which some of them enter very largely. The *phosphate of lime* in particular must be regarded almost in the light of a histogenetic substance, so constantly does it seem to be present in newly-forming tissues; whilst it is also in great demand as the principal consolidating material of bone and tooth. Whether the *carbonate of lime*, the *phosphate of magnesia*, the *fluoride of calcium*, and the *silica* of the blood, are of any other use in it than to supply consolidating materials for the tissues, there is at present no evidence whatever. *Iron*, like the alkaline salts, is an essential constituent of the blood itself, forming a very large percentage of the hæmatin of its red corpuscles; and it is supplied by the blood to various tissues, especially the muscles and the hair, of which also it may be considered an essential component.—The normal proportions of all these substances appear to be chiefly maintained by means of the excretory apparatus, which filters-off (so to speak) any surplus; it being through the Urinary organs that they are chiefly eliminated. And it is by them, too, that the normal proportion of *Water* in the blood is chiefly maintained: the Malpighian apparatus of the kidneys apparently acting as a kind of safety-valve, through which any surplus that remains after the cutaneous, pulmonary, and intestinal exhalants have performed their appropriate duties, is allowed to make its escape.

331. Of the mode in which the substitution of new tissue for that which has become effete, is effected in the process of Nutrition, our knowledge is

at present limited; but there can be little doubt that it nearly always takes place in a manner closely conformable to the first development of each tissue. In some instances there is an obvious *replacement* of the old and dead by the young and active elements: this is the case, for example, in the constantly-repeated production of the Epidermic and Epithelial layers; for whether they are developed from germs imbedded in the subjacent basement-membrane, or from nuclei formed *de novo* in the blastema on its free surface, or by the duplicative subdivision of pre-existing cells, there is a continual succession of new cells, which take the place of those that are cast-off as defunct and useless. So in the growth of Hair, the increase of which takes-place only at its base, we can trace at any period the same development of newly-formed spheroidal cells into horny fusiform fibres, as that which occurred when first the hair began to sprout from the aggregation of epidermic cells at the bottom of its follicle. So, again, in the vesicular tissue which constitutes the essential part of the Nervous centres, there are appearances which indicate that its peculiar cells are in a state of continual development, newly-formed ganglionic vesicles taking the place of those which have undergone disintegration. But there are other textures, whose nutrition is more completely *interstitial;* their elements being more closely coherent, and their newly-formed portions being developed throughout the substance of the old, instead of (as in the case of the epidermis and its appendages) *superficially* or in mere continuity with it. Such is the case, for example, with Muscle, the mode of whose nutrition has not yet been elucidated. We can only infer from analogy, that here too each fibre or fibril will pass, in the course of its development, through the same stages which those of the embryo did when its muscles were first formed. And this analogy seems to derive support, from the presence, in all well-nourished muscles, of bodies which bear the appearance of nuclei; for these, as Mr. Paget remarks, "are not the loitering impotent remains of embryonic tissue, but germs or organs of power for new formation." And it is further confirmatory of this view, that losses of substance of muscle which involve the destruction of these centres of nutrition, are not replaced, like losses of cuticle, by new tissue of the same kind; the power to form it not being inherent in the blood or in the neighbouring parts. Nevertheless it must be admitted that no intermediate stages of development can be traced in the fibres, even of those muscles of the adult which are in most constant use, and of which the nutrition is the most active, that are at all comparable to those which are met-with in the muscular tissues of the embryo.—With regard, again, to the interstitial nutrition of Bones and Teeth, we have no certain knowledge. That some movement of nutritive fluid is continually taking place through them, is made apparent by the effects of madder in gradually tinging even the bones and teeth of the adult, though for such a change a much longer period is required in the adult than in the young animal; how far this movement, however, is subservient to any continual change of substance, still remains doubtful. If the supply of blood be withdrawn from a tooth or from a bone, or even from a part of the latter, the structures thus cut off from connection with the act of nutrition soon die, become detached from the living parts around, and are thrown out of the body. Of this we have a very good example in the annual exuviation of the antlers of the Deer, which is brought about by the choking up of the Haversian canals that give passage to blood-vessels, with concentric osseous deposit. Something of this kind seems to be continually taking place in ordinary Bone, upon a more limited scale; individual Haversian systems being removed by absorption, and being replaced by new formations of the same kind, probably during its whole life, without any change in external configuration.—Of the modes in which the effete particles of tissues whose term of life has expired, or whose vital energy has been exhausted, are removed, our present knowledge is no less imperfect. In the case of those tissues which are *superficially* nourished, a continual loss of substance is obviously taking place, by the exuviation of dead particles *en masse;* this is the case with the whole series of Epithelial and Epidermic cells, which are thrown-off with little previous change, like the leaves of trees, their decay not taking place, for the most part, until after they have become detached from the organism. But the fact is altogether different with regard to those whose nutrition is *interstitial*, especially the Nervous and Muscular tissues; for the decomposition of these would seem to occur in their very substance, its products being taken up by the blood, and subsequently eliminated from it by organs appropriated to that purpose, as is indicated by Chemical evidence.

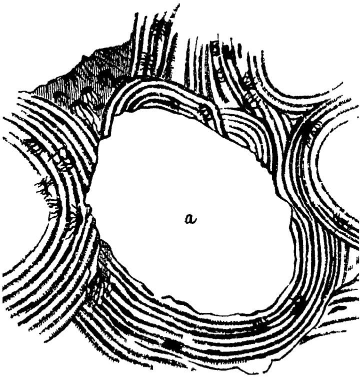
332. A remarkable indication has been recently afforded, by the microscopic examination of Bone, that the older portions of its substance are removed from time to time, and that space is thus provided for the deposit of newly-formed tissue in its stead. For transverse sections of long bones usually exhibit, in some part of their area, irregularly-shaped spaces, having an emarginated, festooned, and often jagged outline (Figs. 71, 72), similar to that found on the surface of bone which has been removed by exfoliation, or to that of the fang of a tooth which has been partly absorbed. There is every indication, from a comparison of the various conditions presented by these 'Haversian spaces,' both as to form, size, and situation, that they are left by the partial or complete removal of 'Haversian systems,' which previously occupied the same situations.

Fig. 71.



Transverse section of compact *Bone*, showing an *Haversian space*, *a*, with its characteristic emarginated outline.

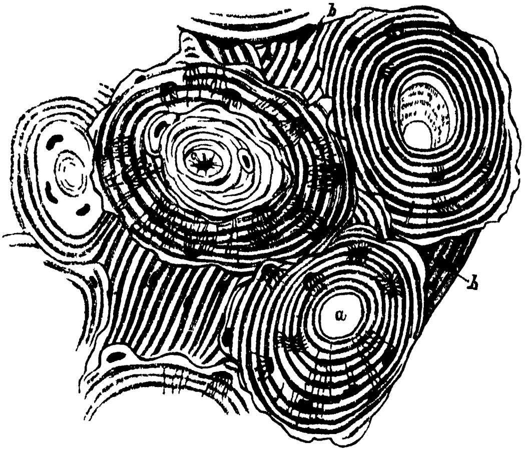
Fig. 72.



The same, from a less compact part of the bone.

They are exceedingly numerous and large in newly-formed bone situated near ossifying cartilage, so as frequently to afford room for the development of two or more 'Haversian systems' in their interior; while in older bone they are far less numerous, and generally less in size, so that by the excavation of one of these spaces within an old 'Haversian system,' a new one may be formed of much smaller dimensions (Fig. 73, *c*). The persistence of portions of those older 'Haversian systems' which have undergone partial absorption, appears to account for the presence of the 'interstitial laminæ' (*b*, *b*), which fill-up the spaces between the existing 'Haversian systems,' and of which, as they have not any obvious centres of nutritive supply, no other satisfactory explanation can be given. Such appearances, indicative of alternate acts of absorption and reproduction, are seen in the bones of old as well as of young or middle-aged subjects; but their frequency diminishes with the increasing age of the individual.*—So far as can be gathered from the foregoing facts, and from others of the same order, the process of interstitial decline and death usually takes place too rapidly for its stages to be perceptible, and is *immediately* followed, in the normal condition of the system, by the removal of the effete particles; so that it is only when this removal is from any cause obstructed, as happens in the cases to be presently cited, that we see any indication of the *stages* through which the disintegrating tissues pass.†

FIG. 73.



Transverse section of compact *Bone*, showing the ordinary appearances:—*a*, Haversian system; *b*, *b*, interstitial laminæ; *c*, new Haversian system within an older one.

333. There is one remarkable form of degeneration, however, which is

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* See the Memoir by Messrs. Tomes and De Morgan 'On the Structure and Development of Bone,' in "Philos. Transact.," 1853, p. 111.

† Fully recognizing the importance of Dr. Lyons' ingenious inquiries on 'Histolysis' (see "Proceed. of Royal Irish Acad.," vol. v. part iii., and "Brit. and For. Med.-Chir. Rev.," vol. xii. p. 454, 532), the Author cannot regard the changes which take place in tissues decomposing out of the body, as throwing much light upon the processes of degeneration that take place during the latter period of their life.

common to nearly all the tissues, and which seems to occur as a normal alteration in many of them at an advanced period of life; this consists in the conversion of their albuminous or gelatinous materials into fat, thus constituting what is known as *fatty degeneration.* That this change is not due to the removal of the normal components of the tissues, and the substitution of newly-deposited fatty matter in their place, but is (in most cases at least) the result of a real conversion of the one class of substances into the other, may now be considered as well ascertained.* And there are certain facts which indicate that this kind of degeneration is a part of the regular series of processes, by which tissues that have served their purpose in the economy are prepared for being removed by absorption; one of the most remarkable being the observations of Virchow† and Kilian‡ with regard to the fatty degeneration of the muscular tissue of the uterus after parturition. So, as Mr. Paget has pointed-out, the fibrinous and corpuscular products of inflammation are often brought into a state fit for absorption, by passing through this intermediate stage; the fibrinous substance being observed to be dotted by granules which are recognized as oil-particles by their peculiar shining black-edged appearance, and at the same time losing its toughness and elasticity, and being no longer rendered transparent by acetic acid; whilst the lymph-cells present a similar increase of shining black-edged particles like minute oil-drops, which accumulate until they nearly fill the cell-cavity, their nuclei at the same time gradually fading and disappearing.§ Thus, then, if the fat, which is one of the products of this retrograde metamorphosis, be absorbed as fast as it is formed, and the effete tissue be replaced by a new production (as seems to be the case with Muscles in a state of healthy activity), there is no appearance of degeneration, and the nutrition is kept up to its normal standard. So if, from the advance of age, or from the insufficient exercise of the muscles, their nutrition take place less rapidly than their waste, whilst the products of their degeneration are still removed, simple atrophy is the result. If, on the other hand, the general conditions being similar, the fat produced in degeneration be not absorbed, but remain in the tissue, an obvious 'fatty degeneration' is the result. This seems most likely to happen either (1) when the fat is thus produced in such excessive amount, that the ordinary rate of its absorption (corresponding with that of its elimination by the combustive process) does not provide for its removal; which will occur when a large amount of tissue is undergoing degeneration at once, as in the case of the uterus after parturition:— or (2) when the blood, being already highly charged with respiratory material, is indisposed to receive an additional amount of fat; and it is probably in part from this cause, that the habitual presence of Alcohol in the blood strongly predisposes to fatty degeneration, as is proved by the very large proportion of intemperate individuals among the subjects of the more aggravated forms of this disorder. For the special aptitude for the combustive process which is characteristic of Alcohol, may give it such a preference in this operation over the ordinary combustive material, that the conversion of the latter by oxidation into carbonic acid and water is kept-back, so long as Alcohol is present; and thus the blood of drunkards becomes so highly charged with fat, that it might be itself considered to be in a state of fatty degeneration.* This distinct evidence of the operation of Alcohol habitually received into the blood in large quantities, affords an obvious indication that the habitual consumption of even a much smaller amount will tend to produce fatty degeneration at more remote periods and in a less aggravated degree; and the participation which this state has been shown to have in the production of a large proportion of the diseases of Old Age,—especially by the changes it induces in the texture of the heart and of the walls of the blood-vessels (which are particularly liable to it),—fully bears out this idea.

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* For an excellent account of the whole subject of Fatty Degeneration, see Dr. Handfield Jones's Articles in the "Brit. and For. Med.-Chir. Rev.," vol. xi. p. 327, and vol. xii. p. 30.

† "Verhandlungen der Gesellschaft für Geburtshülfe," Berlin, vol. iii. p. 17.

‡ Henle and Pfeuffer's "Zeitschrift," vol. ix. p. 1.

§ See Mr. Paget's "Lecture on Surgical Pathology," vol. i. p. 374.

334. It may be stated as a general rule, that no absorption of the materials of tissues can take place, without a previous degeneration such as this, or a more complete decomposition. There is no evidence that any *healthy* tissue is ever thus absorbed, or that any preternatural activity of the absorbent vessels can ever (as formerly supposed) be the *occasion* of a loss of substance; in fact, so long as the vital force is in active operation in a part, and its processes of growth and development are being normally carried-on, such absorption may be considered to be impossible. On the other hand, if a part die *en masse*, it is not removed by absorption, but becomes isolated by the separation and recedence of the living parts, and is then cast-out altogether, even from the interior of the body, as we see in the case of a necrosed bone; its condition being then essentially the same as that of the outer layers of the tegumentary organs, which are cut-off, by their distance from a vascular surface, from all further nutrient change. The difference between these two modes of removal is well seen (as Mr. Paget has remarked) in the case of the Teeth; for the fangs of the deciduous teeth undergo degeneration, when the current of nutrition is diverted towards those which are to succeed them, their materials being slowly decomposed, so as to become soluble, and being gradually removed by absorption, so that nothing is left at last but the crowns of the teeth; on the other hand, the permanent teeth, which are not to be succeeded by others, when no longer receiving their due nutrition, die, and are cast-out entire.

335. Among the conditions of healthy Nutrition, a due supply of Nervous power is commonly enumerated; and it cannot be questioned that the want of such a supply is frequently the source of a perversion of the normal operations. This, however, by no means proves that the formative power is derived from the nervous system; and such an idea is at once negatived by a number of incontestible facts. Yet it may be freely admitted that the right direction and application of this power in Nutrition, may sometimes depend upon guidance and direction afforded

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* The quantity of fat in the blood of drunkards has been found in some cases to be as much as 117 parts in 1000 (Lecanu), the highest estimate of the quantity in health being 8·65 parts. Scharlau has found as much as 30 per cent more carbon in the blood of a drunkard, than in that of a healthy man.—See Dr. Huss's treatise on "Alcoholismus Chronicus," Rokitansky's "Handbuch der allgemeinen pathologischen Anatomie," band iv., and "Brit. and For. Med.-Chir. Rev.," vol. xii. pp. 38, 84.

by the Nervous centres, in the same manner as the Secreting process is capable of being thus affected; in fact, we can scarcely explain in any other mode that influence of mental states upon the nutrient operations, which frequently leads to very important modifications of them.—The whole of this subject, however, will be more appropriately considered hereafter (CHAP. XV).*

3. *Varying Activity of the Nutritive Processes.—Reparative Operations.*

336. Without any change in the *character* of the Nutritive processes, there may be considerable variations in their *degree of activity;* and this, as regards either the entire organism, or individual parts, though most commonly the latter. These variations may be so considerable as to constitute Disease; though there are some which take place, as part of the regular series of Physiological phenomena. Thus, as we have seen, it is to the excess of formative activity, that the increase of the organism in the earlier period of life is due, its 'waste' being at the same time extremely rapid; whilst it is to a corresponding reduction in the regenerative power, and not to positive excess of 'waste' or decay (this, indeed, taking place very slowly), that the gradual decline of the organism in advancing years is to be attributed. So also we find that local as well as general variations may take place, as a part of the regular series of vital phenomena; and this during the period of adult life, as well as in the earlier and later epochs. Thus all those differences in the proportional development of the several parts of the organism, which mark the distinction between the adult and the child, even where (as in the case of a dwarf) there is no difference in stature, result from a decline in the formative capacity of those which are peculiarly adapted to the wants of the earlier stage (the Thymus gland, for example), and from an increased activity of nutrition in those which are destined to the use of the adult, the Generative organs more particularly. And the intermittent activity of the sexual apparatus of the female affords a remarkable example of the same principle; this being marked, not merely in the enormous development of the uterus and mammary glands as a consequence of conception, but in the periodical change which takes place in the ovaries, whereby the ova are matured and thrown-off at certain regular intervals. The decline in the formative power of these same organs, moreover, when as yet the organism in general shows but little indication of deterioration, is another characteristic example of the variation in Nutritive activity resulting from the inherent endowments of the part, and essentially irrespective of the condition of the blood, of the circulation, and of the organism as a whole; although, as formerly shown (§ 200), the production and maintenance of other and apparently unconnected organs are *complementally* dependent upon the formative activity of the Generative apparatus.

337. The abnormal excess of Nutritive change which properly constitutes *Hypertrophy*, appears to depend upon a departure from one or other of the conditions, under which, as already specified, the change normally

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* In the treatment of this subject, the Author has made use of many valuable illustrations contained in the first three of Mr. Paget's "Lectures on Surgical Pathology;" the general doctrines, however, being such as he had himself expressed on many previous occasions.

takes place; namely, the right composition of the blood, a due supply of such blood, and a proper formative capacity in the part itself.—Of the excess of nutrition resulting from the presence of an excess of the peculiar materials of certain tissues in the circulating fluid, examples have already been given (§ 312); it is important to remark, however, that although hypertrophy may be thus induced in any of the tissues which constitute the instruments of *organic* life, yet there is no evidence that either the Nervous or the Muscular apparatus can be forced (so to speak) to an augmentation in bulk, by the mere abundance of their nutritive materials.—With regard, in the next place, to the supply of blood, there can be no doubt that in general an increased flow of blood towards a part is consequent-upon, rather than a cause-of, an excess in its nutritive activity; but still there are cases in which its causative agency may be traced. Various examples of this have been supplied by the experiments and observations of John Hunter, the records of which are left in his Museum. Thus if the spur of a cock be transplanted from the leg to the comb, which is a part far more vascular than that with which it was originally connected, it undergoes an extraordinary augmentation in size; having in one instance grown in a spiral form, until it was six inches long; and in another, curved forwards and downwards like a horn, so that its end needed to be often cut, to enable the bird to bring its beak to the ground in feeding. So, again, it was remarked by Hunter, and has been frequently observed since, that an increased growth of hair often takes place on surfaces to which there is an increased determination of blood as a consequence of inflammation in some neighbouring part, though not from the surface of the inflamed part itself. So it sometimes happens, that when an ulcer of the integuments of the leg has long existed in a young person, the subjacent bone may share in the increased afflux of blood, and may enlarge and elongate. And it seems not improbable that we are to attribute the increased thickness of the cuticle, on parts which are exposed to continual pressure or friction, to the augmented afflux of blood which is determined to the irritated surface.*

338. The greater number of cases of Hypertrophy, however, must undoubtedly be referred to the preternatural formative capacity of the part itself; and this may either be congenital or acquired. Of this congenital excess, we have a remarkable example in the abnormal growth of an entire limb, or of fingers or toes,† which cannot with any probability be referred to an original excess in the supply of blood, the enlargement of the arteries leading towards such parts being almost certainly consequent upon their unusually rapid growth, just as in the case of the uterine and mammary arteries of the pregnant female. The most remarkable instances of the acquirement of increased formative activity, are presented to us in that augmented growth of the nervous and muscular tissues, which is consequent upon the exercise of their functional powers. This may be considered as to a certain extent a normal adjustment of the

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* It is commonly said that local Hypertrophy may be induced by long-continued Congestion; but this is not true hypertrophy; for the bulk of the organ is not augmented by the increased production of its normal tissue, but by the addition of tissue of an inferior type of organization, as in Inflammation.

† A case of hypertrophy of an entire limb was described by Dr. John Reid in the "Edinb. Monthly Journ.," 1843, p. 198; and several cases of hypertrophy of the fingers were described by Mr. Curling in the "Med.-Chir. Trans.," vol. xxviii.

supply to the demand; but there are some instances in which it takes place to such an extent, as to become a positive disease. Thus it not unfrequently happens, that if young persons who naturally show precocity of intellect, are encouraged rather than checked in the use of the brain, the increased nutrition of the organ (which grows faster than its bony case) occasions pressure upon its vessels, it becomes indurated and inactive, and fatuity and coma may supervene. Now although in such cases there may probably have been some congenital tendency to preternatural activity of the brain, which manifested itself in the precocity of intellect, yet there is no doubt that this may be augmented by the 'forcing system' of education; whilst, on the other hand, it may be controlled by a system of management adapted to the peculiar circumstances of the case. Excess of muscular development is peculiarly prone to show itself in the involuntary muscles; but this production is in almost every instance the result of the demand for increased muscular exertion which is consequent upon some obstruction to the usual function of the part. Thus an extraordinary hypertrophy of the muscular coat of the urinary bladder is often seen as a consequence of obstruction to the exit of the urine, through the presence of a stone in the bladder or of a stricture in the urethra; so, again, hypertrophy of the muscular coat of the gall-bladder may take-place as a consequence of obstruction of its duct by a gall-stone; hypertrophy of the muscular coat of any part of the alimentary canal may be induced by the existence of stricture lower down; and even hypertrophy of the heart is generally, if not always, attributable to obstruction to the exit of the blood which it propels, resulting either from stagnation of the pulmonary circulation by the deficient aeration consequent upon disease of the lungs (in which case the hypertrophy is limited to the right side of the heart), or from thickening or induration of the semilunar valves, or from narrowing of the orifices of the aorta and pulmonary artery. It is curious, moreover, to observe that hypertrophy of muscles frequently becomes a source of increased nutrition of the bones to which they are attached: this being manifested, not merely in the augmented bulk of the bones of limbs that are specially exercised, but also in the increased prominence of the ridges and processes to which the muscles are attached. This adaptiveness on the part of the formative activity of the osseous tissue, is curiously manifested also in the relation of the skull to the brain; for if the bulk of the brain be not too rapidly augmented, the skull will enlarge accordingly, and this (in some instances) not merely by the extension of its normal bones, but by the intercalation of new osseous elements, the 'ossa wormiana;' whilst, on the other hand, if there be a diminution in the bulk of the brain, the cranium may adapt itself to this also, by a thickening on its internal surface (or concentric hypertrophy), —this change, rather than a diminution in the entire substance of the skull, being more liable to take place in cases in which the cranial sutures have already closed, and the nutrition of the bone has become inactive.

339. The production of *Tumours* must be considered as a manifestation of an excess of formative activity in individual parts, and as constituting, therefore, a species of Hypertrophy. For a tumour may be composed of the tissues which are normal to the part; as we see especially in the case of those tumours of the uterus, which are made-up of an excess of its ordinary muscular and fibrous elements. But, as Mr. Paget has justly

remarked, "an essential difference lies in this;—the uterus (often itself hypertrophied) in its growth around the tumour maintains a normal type, though excited to its growth, if we may so speak, by an abnormal stimulus; it exactly imitates, in vascularity and muscular development, the pregnant uterus, and may even acquire the like power; and at length, by contractions like those of parturition, may expel the tumour spontaneously separated. But the tumour imitates in its growth no natural shape or construction; the longer it continues, the greater is its deformity. Neither may we overlook the contrast in respect of purpose, or adaptation to the general welfare of the body, which is as manifest in the increase of the uterus as it is improbable in that of the tumour."* A gradation is established, however, between true Hypertrophies and Tumours, by those productions of glandular tissue, which are made-up of the proper substance of the gland with which they are connected, as the mammary, the prostate, or the thyroid, and which (though frequently encysted) are sometimes met-with as outlying portions of the gland itself.—There is another class of objects, to which Tumours come into close relation, and which must be referred, like them, to a local excess of formative activity; these are the 'supernumerary parts' which are not unfrequently developed during fœtal life, as for example, additional fingers and toes. It seems absurd to refer these, formed as they are by simple outgrowth from the limbs to which they are attached, to the 'fusion of germs' which has been hypothetically invoked to explain more important excesses, as those of additional limbs, double bodies, or double heads; and yet from the lower to the higher form of excess, the transition is so gradual, that what is true of the former can scarcely but be true of the latter. Hence even complete 'double monsters' must be regarded, not as having proceeded from two separate germs which have become partially united in the course of their development, but from a single germ, which, being possessed of an unusual formative capacity, has evolved itself into a structure containing more than the usual number of parts, and comparable to that which may be artificially produced by partial fission of the bodies of many of the lower animals.†

340. We can scarcely fail to recognize, throughout this whole series of abnormal productions, the operation of a similar power. In the formation of a supernumerary part, this has been sufficient, not merely to produce the tissues, and to develope them according to a regular morphological type, but to impart to the fabric thus generated a separate and even an independent existence; thus evolving an additional finger or thumb on each hand, a double pair of arms or legs, a double head or trunk, or even a complete double body. In the hypertrophy of a regular or normal part, the new tissues are still developed according to a regular morphological type; but they have not the power of individualizing themselves (so to speak), and are so incorporated with the normal elements as to augment the size of the existing organ. In the formation

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* See his "Lectures on Surgical Pathology," vol. ii. p. 2; also Dr. Handfield Jones in "Brit. and For. Med.-Chir. Rev.," vol. xiii. p. 330; and Dr. Bristowe in "Trans. of Pathol. Soc.," vol. iv. p. 218.

† See "Princ. of Comp. Phys.," § 475; Prof. Vrolik in "Cyclop. of Anat. and Phys.," art. 'Teratology,' vol. iv. p. 976; and Prof. Allen Thomson on 'Double Monstrosity,' in "Edinb. Monthly Journal," June and July, 1844.

of a tumour, on the other hand, whilst its component tissues are themselves perfectly formed, and have a marked power of independent growth, the mass composed of them is altogether amorphous, its configuration being usually determined rather by the physical conditions under which it is produced, than by any peculiar tendencies of its own; so that we recognize the action of the formative power, undirected by that morphological *nisus*, which normally models (so to speak) the growing tissues into the likeness of the organ to which they belong. But further, in many of the large class of tumours distinguished as 'malignant,' the development of tissue has not gone to the extent of producing any of those species of which the body is normally constituted; and in this respect, as well as in their tendency to rapid degeneration, the vital endowments of their elements must be reckoned as below those of the normal tissues.—It is not always easy to draw the line between certain tumours and supernumerary parts, especially when the production of the former is symmetrical; but the first appearance of the latter never takes place save during embryonic life, and their structure is more complex, and is more conformed to the plan and construction of the body at large, than is that of tumours, whose production may take-place at any period of life. And between those tumours which are known as 'piliferous' and 'dentigerous cysts,' and those encysted embryoes (usually incomplete in their formation) which are sometimes found in the bodies even of males, it is impossible to establish any line of demarcation sufficiently precise, to prevent our recognizing them as all having the same origin, and being expressions of the same power,—the simple cyst being a kind of rude attempt at the production of a distinct individual,—and the encysted embryo being but the result of an unusually high development of a proliferous cyst.

341. The state of *Atrophy* is in all respects the very opposite of that of Hypertrophy; consisting in such a reduction in the rate of formative activity of parts, as compared with that of their 'waste,' that their nutrition is no longer maintained at its previous standard; so that they are gradually reduced in bulk, or degenerate into some inferior histological type, or (which is more common) undergo both diminution and deterioration at the same time. It is important to bear in mind, that Atrophy may take-place, either locally or generally, from an unusually-rapid disintegration of the tissues, uncompensated by a corresponding increase in the rate of their nutrition: Of such local atrophy, we have a characteristic example in the rapid reduction of the bulk of the uterus after parturition, and of the mammary glands after the sudden cessation of lactation; of the general, we see an illustration in that rapid wasting of the system, which takes place in the irritable state that results from excessive and prolonged exertion of body or anxiety of mind, especially when accompanied with want of sleep, the increased disintegration being marked by the presence of an unusual amount of urea and of the alkaline phosphates in the urine. But in the ordinary forms of Atrophy, there is not merely a *relative* but an *absolute* reduction in the rate of the formative process, or a lowering of its standard of perfection; and here also we have to look for its causes, on the one hand, in the condition and supply of the blood, and, on the other, in the formative capacity of the tissues themselves.—The Atrophy dependent upon an insufficient supply of nutritive materials, may be

either general or partial. General atrophy, or emaciation, is a necessary result of deficiency of food; but it may also proceed from an imperfect performance of the assimilating processes, whereby the nutritive materials do not receive their requisite elaboration, as in cases of disease of the mesenteric glands; or from an unusual energy of the metamorphic processes, whereby the azotized constituents of the food are decomposed into excrementitious products, without undergoing assimilation at all, as seems to be the case in diabetes. Of the atrophy of a particular tissue, consequent upon the deficiency of its proper materials in the blood, we have an example in the reduction of the adipose, when there is no surplus of fatty matter to serve for its nutrition, but on the other hand a withdrawal of the contents of the fat-cells into the circulating current, whilst the nutrition of the muscular and other azotized tissues may proceed with its usual vigour.—Instances of complete local atrophy, or gangrene, resulting from deficiency in the supply of blood to a part, are by no means unfrequent; but it is less common to meet with a prolonged diminution in the rate of nutrition from such a cause, since a partial obstruction to the circulation is usually removed after a short time by the enlargement of the collateral vessels. Yet there are peculiar circumstances under which this does not take place; thus Mr. Curling has shown that atrophy may occur in that portion of a fractured bone which is cut-off from the direct supply of blood through the great medullary artery; the circulation being restored by anastomosis to such an extent as to prevent the death of the bone, but not so completely as to support vigorous nutrition.*

342. The most frequent cause of Atrophy lies, however, in the deficiency of formative power in the tissues themselves, arising from the decline of that capacity which they inherit from the germ. This decline, as already shown, takes place in the body at large, as a part of the regular order of things, with the advance of years, and also normally occurs in particular organs at earlier periods of life; but it sometimes takes place prematurely, either in the body at large, or in particular organs, so that they undergo a wasting or degeneration without any ostensible cause. Thus it is not at all uncommon for Articular Cartilages to be almost entirely destroyed through defect of nutrition, without any pain or other symptoms to call attention to the change in progress;† and many similar cases might be cited. There is reason to believe that 'fatty degeneration,' the form under which degeneration most commonly presents itself (§ 333), is in reality far more frequent than simple wasting; but it attracts less notice, because the bulk of the tissues is little or not at all diminished; and it is only when their function becomes impaired, that attention is seriously drawn to the change. This form of Atrophy can seldom be attributed to antecedent diminution in functional activity; for it is most common in organs upon which there is the most constant demand for the energetic performance of their respective duties, as, for instance, in the heart, the kidneys, and the liver. But the formative activity of Muscles and Nerves is so closely dependent, as already several times pointed-out, upon the active exercise of their functional powers, that atrophy is certain to supervene if this be interrupted; and this atrophy may or may

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* "Medico-Chirurgical Transactions," vol. xx.

† See Redfern, "On Anormal Nutrition in Articular Cartilages," p. 65.

not present itself under the form of fatty degeneration; a shrinkage of the parts, concurrently with the production of an increased amount of fat in them, being perhaps the mode in which it most frequently takes place. Atrophy of one part, moreover, may be dependent upon atrophy or imperfect functional activity of another, if the two be so related in their normal functions, that a decline of one involves a corresponding decline in the other. Thus if a motor nerve be paralyzed, the muscles which it habitually calls into action will be atrophied; and this will equally happen, whether the want of motive power depend upon a deficient production of it in the nervous centres, or upon an interruption to its conduction through the trunks.* On the other hand, if the muscles of a part undergo degeneration from want of use (as in disease of the hip-joint), the nerves which supply them also suffer. The same is the case in regard to the nerves and organs of sense; for atrophy of the eye will occasion atrophy of the optic nerve, and destruction of the optic ganglia will induce atrophy of the eyes and optic nerves. Even the bones of a limb will suffer, in cases of atrophy of the muscles consequent upon disuse; for in an experiment made by Dr. J. Reid, to determine the effect of artificial exercise in maintaining the nutrition of muscles whose nerves had been divided, the bones of the quiescent limb only weighed 81 grains, whilst those of the exercised limb weighed 89 grains.†—It is an important fact, which was first pointed-out by Mr. Paget,‡ that when fatty degeneration is commencing in any tissue, which is characterized by the persistence of its nuclei, it is in the nuclei that the first alterations are seen; for they become pale and indistinct, and may even disappear altogether, almost before any other change is discernible in the contents of the cells or tubes to which they appertain; but in atrophy from mere decrease, this disappearance of the nuclei does not occur.

343. *Reparative Process.*—The nutritive operations take place with extraordinary energy and rapidity in the process of *Reparation;* by which losses of substance occasioned by injury or disease are made good. In its most perfect form, this process is exactly analogous to that of the *first development* of the corresponding parts; and its results are as complete in the one case as in the other. In fact, among the lowest tribes of Animals, we find these two conditions blended, as it were, together; for

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* The Author had some time ago under his observation a case in which three males of a family progressively became affected, between the ages of 3 and 5 years, with fatty degeneration of the muscles, which proceeded in the most advanced case to the almost complete obliteration of their normal structure. This change had been considered by many eminent Practitioners to be idiopathic; that is, to have its primary origin in the muscular tissue; and the measures which had been employed to arrest it had been of no avail whatever. It was a strong argument, however, against such a view of the case, that, in the *heart* of the eldest son, who died of fever at the age of 16, no fatty degeneration could be discovered; and on making inquiry into the history of the parents and of their families, ample evidence was discovered for the belief, that the disease was dependent upon the want of functional power in the nervous centres. Acting on this view, it was recommended that the muscular system should be kept as much as possible in a state of active exercise, and that a weak galvanic current should be frequently transmitted through the limbs from the spine. This treatment proved so far successful, that the progress of the disease appeared to be arrested in the most-advanced case, whilst a decided improvement took place in the condition of a younger child, who was previously passing rapidly into a state resembling that of his elder brothers.

† "Physiological, Anatomical, and Pathological Researches," p. 10.

‡ "Lectures on Surgical Pathology," vol. i. p. 106.

the process of reparation may be carried in them to such an extent, as to reproduce the whole organism from a very small portion of it. In the Hydra, or Fresh-water Polype, there would seem to be scarcely any limit to this power; for, even if the body of the animal be minced into small fragments, every one of these can produce a new and perfect being. In this manner, no less than forty have been artificially generated from a single individual.—In ascending the Animal scale, we find this reparative power less conspicuous, because limited in its exercise to particular tissues and to comparatively insignificant parts of the body;* and in Man, as in other warm-blooded Vertebrata, the regenerative power is for the most part restricted in its exercise, as Mr. Paget has pointed-out,† to three classes of parts;—namely, (1). "Those which are formed entirely by nutritive repetition, like the blood and epithelia (their germs being continually generated *de novo* in the ordinary condition of the body); (2). Those which are of lowest organization, and (what seems of more importance) of lowest chemical character, as the gelatinous tissues, the areolar and tendinous, and the bones; (3). Those which are inserted in other tissues, not as essential to their structure, but as accessories, as connecting or incorporating them with the other structures of vegetative or animal life, such as nerve-fibres or blood-vessels. With these exceptions, injuries or losses are capable of no more than repair in its limited sense; *i.e.* in the place of what is lost, some lowly-organized tissue is formed, which fills up the breach, and suffices for the maintenance of a less perfect life."—Yet, even thus restricted, the operations of this power are frequently most remarkable; and are in no instance, perhaps, more strikingly displayed, than in the re-formation and remodelling of an entire Bone, when the original one has been destroyed by disease. That this power is intimately related to that by which the organism is normally built-up and maintained, is evident, not merely from the peculiar mode in which it is exercised,—its tendency being always to reproduce each part in the form and structure characteristic of it at the particular period of life, and not according to its embryonic type,—but also from the fact that it is more effectual in the state of growth than in the adult condition, and that it can do far more in the embryonic state, when development as well as growth is taking place, than after the developmental process has ceased. In fact, as Mr. Paget has remarked (loc. cit.), its amount at different periods of existence, as in different classes of animals, seems to bear an inverse ratio to the degree of development which has already taken place. Thus it is well known to every Practitioner, how much more readily and perfectly the lesions resulting from accident or disease are repaired in childhood and youth, than they are after the attainment of the adult state. And there is evidence that during embryonic life, the regeneration of lost parts may take place in a degree to which we have scarcely any parallel after birth: for Prof. Simpson has brought-together numerous cases, in which, after 'spontaneous amputation' of the limbs of a fœtus, occurring at an early period of gestation, there has obviously been an imperfect attempt at the re-formation of the amputated part from the stump;‡ and it seems probable, from the history of normal development, that in the cases in which perfect hands and feet have been present without the corresponding limbs, these hands and feet have been secondary productions from the stumps of amputated limbs, since any original defect of development would have affected the hands and feet rather than the arms and legs. There are occasional examples, moreover, in which this regenerative power has been prolonged to an unusually-late period: thus an instance is recorded, on authority that can scarcely be doubted, of the twice-repeated reproduction of a supernumerary thumb, after it had been twice completely removed;* and the Author has been assured by a very intelligent surgeon, that he was cognizant of a case in which the whole of one ramus of the lower jaw having been lost by disease in a young girl, the jaw had been completely regenerated, and teeth were developed and occupied their normal situations in it.†

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* See "Princ. of Comp. Phys.," chap. xi., sect. 3. † Op. cit., p. 164.

‡ These cases were brought by Prof. Simpson before the Physiological Section of the

344. It has been a general opinion among British surgeons (founded upon what they believe, but erroneously, to have been the doctrine of Hunter), that Inflammation is essential to the process of Reparation. There is no doubt that, as usually conducted, the healing of wounds is attended by a greater or less degree of Inflammation; but it does not thence follow that this morbid condition is essential to the renewal of the healthy state; and in fact it can be shown that, in the majority of cases, the occurrence of Inflammation is injurious rather than beneficial. It was by Dr. Macartney that the first clear enunciation of this important truth was made; and his conclusions, founded upon a philosophical comparative survey of the operations of Reparation and Inflammation as performed in the different classes of animals,—namely, "that the powers of reparation and reproduction are in proportion to the indisposition or incapacity for inflammation;—that inflammation is so far from being necessary to the reparation of parts, that, in proportion as it exists, the latter is impeded, retarded, or prevented;—that, when inflammation does not exist, the reparative power is equal to the original tendency to produce and maintain organic form and structure;—and that it then becomes a natural function, like the growth of the individual, or the reproduction of the species,"‡—may be regarded as substantially correct, although requiring some modification in particular cases.

345. The simplest of all the methods of healing of an open wound, is that which is termed by Dr. Macartney 'immediate union.' It is often seen in the case of small incised wounds, such as cuts of the fingers, or the incision made in venesection, in which the two edges can be brought into close approximation, so that they grow-together without any connecting medium of blood or lymph; but it sometimes occurs in larger ones,§ and as it is the best imaginable process, the surgeon ought to

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British Association, at its Meeting in Edinburgh, Aug. 1850. The Author, having had the opportunity of examining two living examples, as well as Prof. Simpson's preparations, is perfectly satisfied as to the fact.

* See Mr. White's Treatise on the "Regeneration of Animal and Vegetable Substances," (1785) p. 16. A case is now under Dr. Carpenter's observation, where the reproduction of a supernumerary digit, after removal, has occurred *once*, and a second operation is postponed till the child has ceased to grow.—Ed.

† For analogous cases, see "Wagner on Resections," Syd. Soc. Transl., p. 137.

‡ Dr. Macartney's "Treatise on Inflammation," p. 7.

§ Mr. Paget mentions a case of extirpation of a mammary tumour, in which the greater part of the wound was found to have healed after this fashion; the skin and fascia having so firmly adhered, that no indication existed of their previous detachment; and no effusion *favour it as much as possible, by procuring the most exact coaptation of* the wounded parts, and by *repressing any tendency to inflammation which will interfere with it. This is the* mode of union which was spoken-of by John Hunter as 'healing by the first intention.' He supposed that the union takes place through the medium of the blood intervening between the lips of the wound, which undergoes organization into a connecting tissue; but it is now certain that although blood *may* become organized, especially when effused into a wound secluded from the air, yet that its intervention opposes, rather than favours, healing by immediate union.

346. That which is commonly known amongst British Surgeons as 'healing by the first intention,' is that which was designated by Hunter as 'union by adhesion' or by 'adhesive inflammation.' This process takes-place in the case of incised wounds, of which the edges are not brought into perfect coaptation, or in which some inflammatory action is present, which gives-rise to the effusion of plastic lymph. In either case, the connection is finally re-established by the organization of the lymph, into which vessels pass from both surfaces; but the intervention of this bond is manifested in the persistence of the cicatrix, which is quite distinguishable by its peculiar appearance from the surrounding tissue. A very good example of this process, as it takes-place under favourable circumstances, is presented after operations for hare-lip; the wound left by which, however, may partly heal by 'immediate union.' Even the moderate effusion of lymph, to a degree that is altogether salutary, cannot be regarded as alone sufficing, under such circumstances, to constitute Inflammation. But it is well known that if a slight wound, which is thus healing, be provoked to an increased degree of inflammation, its progress is interrupted; and all the means which the Surgeon employs to promote union are such as tend to prevent the accession of this state.—The only case in which the concurrence of Inflammation can be regarded as salutary, is that in which there is a deficiency of Fibrin in the blood, causing a deficient *organizability* of the lymph. It has been seen that the amount of fibrin is rapidly increased by inflammation (§ 178): and the Surgeon well knows that a wound with pale flabby edges, in a depressed state of the system, will not heal, until some degree of Inflammation has commenced. But when the inflammatory state has developed itself, in however trifling a degree, there is always a risk of its proceeding further, and occasioning a degeneration of the plastic material, so that the formation of pus-cells and the effusion of purulent fluid take place, instead of the development of uniting tissue.

347. The reparation of wounds, in which there has been so great a loss of substance that neither immediate union nor adhesion by a thin layer of coagulable lymph can take place, is accomplished by the gradual development of new tissue from the 'nucleated blastema' with which the cavity is first filled. But this may take place in different modes, according to the degree in which it is disturbed by the Inflammatory process; and it should be the great object of the Surgeon to procure the most favourable method of its performance. It has been shown by Mr. Paget* that the mode in which the process of filling-up is accomplished, differs essentially

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of coagulable lymph, or production of a connecting tissue, being detectible by microscopic examination. ("Lectures on Surgical Pathology," vol. i. p. 193.)

[*] Op. cit.

according as the wound is subcutaneous, or is exposed to air. In the former case, the nucleated blastema is gradually developed into fibrous tissues without any loss, and usually with freedom from local inflammation (beyond what may have been requisite for the production of the plastic fluid), as well as from constitutional irritation. In the latter case, the nucleated blastema is developed into cells; and those on its exposed surface are unable, either from degeneration or from imperfect development, to pass-on to any higher form of organization, but take-on the characters of pus-cells, and are only fit to be cast-off. Hence there is a continual loss of plastic material, the amount of which, in the case of an extensive suppurating sore, forms a most serious drain upon the system; whilst, at the same time, the local inflammation gives-rise to more or less of constitutional disturbance, and the formation of new tissue is by no means so perfect as in the preceding case. In cold-blooded animals, however, the contact of air does not produce this disturbance; and we see wounds with extensive loss of substance gradually filled-up in them by the development of new tissue, without any suppuration or other waste of material, very much as in the subcutaneous wounds of warm-blooded animals. This method of healing, which has been termed by Dr. Macartney the 'modelling process,' is nothing else than healing by granulations under the most favourable circumstances; and to procure this should be the endeavour of the Surgeon, who too frequently considers suppurative granulation as the only means by which an open wound can be filled-up. The difference between the two modes of reparation is often one of life and death, especially in the case of large burns on the trunk in children; for it frequently happens that the patient sinks under the great constitutional disturbance occasioned by a large suppurating surface, although he has survived the immediate shock of the injury.—Now the means adopted by Nature to bring this about, in warm-blooded animals, is the formation of a *scab;* which reduces the wound more nearly to the condition of a subcutaneous one, so that the reparative growth and formation of new tissue take place (under favourable circumstances) without any suppuration, and with scarcely any irritation; the subsequent cicatrix, too, being much more like the natural parts, than are any scars formed in wounds that remain exposed to the air. In the Human subject, however, the process is far less certain than it is among the lower animals, owing to the liability to inflammation in the wounded part, and the consequent effusion of fluid, which produces pain, compresses the wounded surface, or forces off the scab, with great discomfort to the patient, and retardation of the healing. Small wounds, however, in persons of good habit of body, and in parts which can be completely kept at rest, readily heal in this manner; and large wounds have been known to close, in the same desirable mode, beneath a clot of inspissated blood. In fact, among 'uncivilized' nations, whose habits of life are favourable to health,—their bodies being continually exposed to fresh air, their food wholesome and taken in moderation, and their drink water or other unstimulating liquids,—there seems to be as great a tendency to this method of reparation, as exists among the lower animals; and the difficulty of procuring it among the members of 'civilized' communities, is owing, without doubt, to the *unnatural* conditions under which they too frequently live. Seeing as we continually do, the effects of foul air, of habitual excess in diet, and of the constant abuse of stimulants, in impairing that form of the reparative process which must be regarded as the *least* favourable, namely, the closure of a wound by suppurating granulations, it is very easy to comprehend, that, to induce the *most* favourable method, the most perfect freedom from all pernicious agencies should be required.

348. The most effectual means of promoting this kind of Reparative process, and of preventing the interference of Inflammation, vary according to the nature of the injury. The exclusion of air from the surface, and the regulation of the temperature, appear the two points of chief importance. By Dr. Macartney, the constant application of moisture is also insisted on.* He states that the immediate effects of injuries, especially of such as act severely upon the sentient extremities of the nerves, are best abated by the action of "*steam* at a high but comfortable temperature, the influence of which is gently stimulant, and at the same time extremely soothing." After the pain and sense of injury have passed away, the steam, at a lower temperature, may be continued; and, according to Dr. M., no local application can compete with this, when the Inflammation is of an active character. For subsequently restraining this, however, so as to promote the simple reparative process, Water-dressing will, he considers, answer sufficiently well; its principal object being the constant production of a moderate degree of Cold, which diminishes, whilst it does not extinguish, sensibility and vascular action, and allows the Reparative process to be carried-on as in the inferior tribes of animals. The reduction of the heat in an extreme degree, as by the application of ice or iced water, is not here called-for, and would be positively injurious; since it not only renders the existence of Inflammation in the part impossible, but, being a direct sedative to all vital activity, suspends also the process of restoration. The efficacy of Water-dressing in injuries of the severest character, and in those which are most likely to be attended with violent Inflammation (especially wounds of the large joints), has now been established beyond all question; and its employment is continually becoming more general.†—Other plans have been proposed, however, which seem in particular cases to be equally effectual. To Dr. Greenhow, of Newcastle, for instance, it was accidentally suggested, a few years since,‡ to cover the surface of recent burns with a liquefied resinous ointment, so as to form an artificial scab; and he states that in this manner suppuration may be prevented, even where large sloughs are formed; the hollow being gradually filled-up by new tissue, which is so like that which has been destroyed, that no change in the surface manifests itself, and none of that contraction, which ordinarily occurs even under the best management, subsequently takes place.—A plan moreover, been proposed for preventing suppuration and prom reparation by the 'modelling' process, which consists in the application *warm dry air* to the wounded surface. Although the experiments yet published have not been entirely satisfactory, they seem to show that whilst the process of healing may be slower under treatment of this kind, it is attended with less constitutional disturbance than is often unavoid-

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* "Treatise on Inflammation," p. 178.

† See an account of the results of this treatment by Dr. Gilchrist, in "Brit. and For. Med. Rev.," July 1846, p. 242.

‡ "Medical Gazette," Oct. 13, 1838.

able in the ordinary method; and that it may, therefore, be advantageously put in practice in those cases, in which the condition of the patient requires every precaution against such an additional burthen,—as after amputation in a strumous subject.*

349. When the process of healing of an open wound by Suppurative Granulation is attentively watched, it is seen that the first stage is the formation of a 'glazing' on the exposed surface, which closely resembles the buffy coat of the blood, being composed of coagulated fibrin and colourless corpuscles; in this manner a sort of imperfect epithelium may be formed, within half an hour after the surface has been laid-bare. The increase of this glazing is the prelude to the formation of granulations; but whilst it is going-on, there is, in and about the wound, an appearance of complete inaction, a sort of calm, in which scarcely anything appears except a slight oozing of serous fluids from the wound, and which continues from one day to eight, ten, or more, according to the nature and extent of the wounded part, and the general condition of the body. "This calm," says Mr. Paget, "may be the brooding-time for either good or evil; whilst it lasts, the mode of union of the wound will, in many cases, be determined; the healing may be perfected, or a slow uncertain process of repair may be but just begun; and the mutual influence which the injury and the patient's constitution are to exercise on one another, appears to be manifested more often at or near the end of this period, than at any other time." The cessation of this period of calm, and the active commencement of the reparative operations, are marked by the restoration of the flow of blood in the vessels of the wounded part; but the current is not altogether normal, being slower but fuller than natural, so that on the whole more blood than usual passes through the capillary plexus. This increased afflux of blood is followed by effusion of plastic material in increased proportion; and it is from this effusion that the granulating process properly commences.—The plastic material effused upon the surface of an *open* wound, is first developed into cells; and these cells, in the deeper portions of the effusion, are metamorphosed into fibrous tissue, of which the substance of the granulations is composed. Those which are formed upon the surface, however, are converted into pus-cells; in some instances (as Mr. Paget has pointed-out) by degeneration from a higher development; in other cases by an originally imperfect development: and thus the granulation-surface is constantly in a state of morbid action, and a large proportion of the plastic material is completely wasted. The layer of pus, however, serves as a sort of epithelium for the subjacent granulation-tissue, in which we find not only a complete formation of cells, but a commencement of the metamorphosis of these cells into fibres, before blood-vessels make their appearance in the tissue. These blood-vessels are formed by "out-growth" from the subjacent capillaries. From the investigations of Mr. Liston, it appears that the vessels of the subjacent tissue are much enlarged, and assume a varicose character. The bright red colour of the granulations, however, does not depend on their vascularity alone; for the cells themselves, especially those most recently evolved, are of nearly as deep a colour as the blood-corpuscles; and the sanguineous exudation which follows even the

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* See M. Jules Guyot, "De l'emploi de la Chaleur dans le Traitement des Ulcères, &c."

slightest touch of the granulating surface, does not proceed from blood effused from the newly-formed vessels only; for the red fluid shed in this manner contains, besides blood-discs, newly-developed red cells, ruddy cytoblasts, pale granules, and reddish serum. It is a common property of animal cytoblasts, that they present a reddish colour on their first formation, when in contact with oxygen; but this hue they lose again, whether they advance to perfect development and become integral parts of a living tissue, or die and degenerate.

350. The process of Suppurative Granulation, then, appears to differ from the process of granulation as it takes place in *closed* wounds, or in a warm moist atmosphere (the 'modelling-process' of Dr. Macartney), essentially in this:—that a large part of the exudation-corpuscles deposited on the wounded surface degenerate into pus in the former case, whilst none are thus wasted in the latter;—but that the existence of inflammation occasions a more copious supply of fibrin in the former case, and increases its tendency to become organized: the filling-up of a wound with granulations being thus a much more rapid process, than that renewal of the completely-formed tissues which may take place in the absence of inflammation. The imperfect character of the granulation-structure is shown, by the almost complete disappearance of it after the wound has closed-over. The portion of it in immediate contact with the subjacent tissue, however, appears to undergo a higher organization; for it becomes the medium by which the cicatrix is made to adhere to the bottom of the wound. It is very liable to undergo changes which end in its disintegration; as is evident from the known tendency to re-opening, in wounds that have been closed in this manner.

351. When two opposite surfaces of granulations, well developed, but not yet covered with cuticle, are brought into apposition, they have a tendency to unite, like the two original surfaces of an incised wound. This method of union, which was noticed by John Hunter, has been appropriately termed 'secondary adhesion' by Mr. Paget. The surgeon may frequently have recourse to it with great advantage, when primary adhesion is impossible, and when the filling-up of the wound with granulations would be a tedious process, and very exhausting to the patient. In applying it to practice, it is essential to success, first, that the granulations should be healthy, not inflamed or profusely secreting, nor degenerated as those in sinuses commonly are; and secondly, that the contact between them should be gentle but maintained: it seems desirable, also, that the granulation-surfaces should be as much as possible of equal development, and alike in character.*

4. *Abnormal Forms of the Nutritive Process.*

352. Under the preceding head we have considered the chief variations in the degree of activity that are witnessed in the ordinary or normal conditions of the Nutritive process,—those conditions, namely, in which the products are adapted, by their similarity of character, to replace those

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* On the whole subject of the Reparative Processes, see Mr. Paget's admirable "Lectures on Surgical Pathology" (vol. i. Lect. vii.-xii.); from which many of the foregoing statements and doctrines are adopted.

which have been removed by disintegration. But we have now to consider those forms of this process in which the products are *abnormal*,—being different from the tissues they ought to replace. We shall confine ourselves to a brief examination of a few of some of the most important of these states; and that which first claims our consideration, on account of the frequency of its occurrence and the importance of its results, is *Inflammation.*—Although Pathologists have been accustomed to look for the 'proximate cause' of the phenomena which essentially constitute the Inflammatory state, or, in other words, for the first departure from the normal course of vital action, in the enlarged or contracted dimensions of the blood-vessels of the inflamed part, or in the altered rate of movement of the blood through it, yet it may now be safely affirmed that these are only secondary alterations, depending upon an original and essential perversion of that normal reaction between the blood and the tissues, which constitutes the proper Nutritive process. This perversion manifests itself (1) in a diminution in the formative activity of the tissues, leading to their degeneration and death; (2) in an augmentation of the plastic components of the blood, proceeding in all probability, as Virchow has suggested, from their increased local production, and subsequent conveyance into the circulating fluid by the lymphatics; and (3) in these newly-formed materials appearing either in a state in which they may pass into a low form of organized tissue, or in such a degraded condition that they are altogether unorganizable, and are fit only to be cast-out from the body. Each of these phenomena requires a separate examination, both as to its causes and its consequences.

353. Although it has been customary to speak of Inflammation as a state of 'increased action' in the part affected,—of which increased action, the augmentation in the bulk and weight of an inflamed part, and in the quantity of blood which passes through it, together with its higher temperature and more acute sensibility, would seem to furnish sufficient evidence,—yet all these signs are found to be deceptive, when they are more closely examined; and the conclusion is forced upon us, that the vital power of the part is really *depressed* rather than exalted. For the increase in bulk and weight is not due to such an augmentation of its proper tissue, as would truly constitute Hypertrophy; on the contrary, even in the slightest forms of Inflammation there is such a diminution in the rate of its nutrition, as really constitutes Atrophy; and such augmentation of the solid mass as may take place, is produced by the passage of the fluid which should properly have been applied to the nutrition of the part, into an organized tissue of the lowest kind, and this in virtue rather of its own plasticity, than of the vital force which it derives from the tissues which it infiltrates. That there has been an atrophy rather than a hypertrophy of the proper fabric of the part, becomes evident enough when the inflammation has passed-away, and this newly-formed tissue undergoes degeneration and absorption. The only tissues in which there is any appearance of increased formation during the inflammatory state, are those which correspond in their low type of organization with the new tissue thus generated: namely, the areolar and other simple fibrous tissues, and also the osseous, in all of which, as Virchow has shown, the cells undergo remarkable increase, constituting what he has termed Hyperplasia, or a formation of new elements, in opposition to Hypertrophy, or

an increase in the nutrition of existing parts.* When the Inflammation is more severe, the tendency to degeneration in the proper tissues of the part becomes very obvious: for it is by their *interstitial* decay and removal, that the cavity of an *abscess* is formed; it is by their *superficial* death and absorption or solution, that *ulceration* takes place; and it is in the death of a whole mass at once, that *gangrene* consists.

354. That a diminution in the formative activity of the Tissues is an essential characteristic of the Inflammatory state, further appears from the study of its Etiology; for whether the causes to which the inflammatory attack may be traced are *local* or *general*, acting primarily upon the tissues of the part, or first affecting the blood, their operation is essentially the same. Thus the *local* causes are all obviously such as tend either directly to depress the vital powers, or to elevate them at first, and then to depress them by exhaustion. Of the former kind are cold and mechanical injury; also many chemical agents, whose operation tends to bring back the living tissues to the condition of inorganic compounds. Under the latter category are to be ranked all those agencies, which produce over-exertion of the functional power of the part; amongst which may be named heat, when not so excessive as to produce a directly destructive effect. Now cold, heat, chemical agents, and mechanical injury, when operating in sufficient intensity, at once *kill* the part, by entirely destroying, instead of merely depressing, its vital powers; and it is on the borders of the dead part, where the cause has acted with less potency, that we find the inflammatory state subsequently presenting itself.—On the other hand, there can be no doubt that many inflammations have their origin in morbid conditions of the Blood, which, without any other cause whatever, may determine all the other phenomena. This is most obvious with regard to those of a 'specific' kind; but it is also probably true of the majority of the so-called spontaneous or constitutional, as distinguished from traumatic inflammations. We seem, indeed, to be able to trace a regular gradation, between inflammatory attacks which are entirely traceable to the introduction of a poison into the blood, and those which result from causes purely local. Under the first head, we may unquestionably rank such inflammatory diseases as are produceable by inoculation, the eruptive fevers for example; and scarcely less thoroughly demonstrated are the cases of rheumatism and gout, and many inflammations of the cutaneous textures, which, when occurring in the chronic form, tend to exhibit a regular symmetry (§ 198). In all such cases, the local affections are the external signs of the general affection of the blood, just as are the inflammations produced by the introduction of arsenic or of other irritant poisons into the circulation; and they may in fact be reasonably attributed to the impairment of the formative activity of the parts upon which these poisons fix themselves, in virtue of their 'elective affinity' (§ 202), just as the peculiar functional activity of the nervous centres is affected by narcotic poisons. And this view of the really-local action of what are primarily regarded as general or constitutional causes of inflammation, is confirmed by the fact, that the localization of the perverted nutritive condition is often determined (as both Dr. W. Budd and Mr. Paget have remarked) by a previous or

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* "Cellular Pathology," 1860, p. 403.

concurrent weakening or depression of the vital activity of the part. Thus a part which has been the seat of former disease or injury, and which has never recovered its vigour of nutrition, is always more liable than another to be the seat of local manifestation of blood-disease; it is, in common language, the 'weak part.'* And it frequently needs such a concurrent operation of a local depressing cause, to fix and develope the action of the constitutional cause, or blood-disorder; thus, a rheumatic or gouty diathesis may exist for some time (as when, to use a common expression, the disease is 'flying about' the patient), and yet the poison may not have sufficient potency to produce an attack of acute inflammation, until the vitality of some particular organ becomes depressed by cold, over-exertion, or some similar influence, which would not have itself engendered the diseased action, had it not been for the concurrence of the morbid condition of the blood.—Thus we seem justified in concluding, that, whether the causes of Inflammation act directly upon the tissues of a part, or whether they act upon it through the intermediation of the blood, their effect is to produce a depression in its vital powers, which manifests itself in *a deficient as well as abnormally directed formative activity*, and in *an increased tendency to degeneration;* and that this is one of the primary and essential conditions of Inflammation.

355. This view is by no means inconsistent with the occurrence of other manifestations of Inflammation which have been supposed to indicate 'increased action;' and, in fact, it is in such striking accordance with the phenomena presented by the movement of the blood, when these are interpreted by the principles already laid-down, as to afford a powerful confirmation to both doctrines. The usual condition of the vessels of an inflamed part, is one of dilatation; and this may be fairly attributed to the lowered vitality of their walls, whereby they yield too readily to the distending force of the current of blood. But this current moves too slowly; and its retardation may gradually increase, in the part most intensely inflamed, to the point of complete stagnation. Now this altered rate of movement cannot be attributed to any general cause: nor can it be accounted-for by the change in the diameter of the vessels; for, on the one hand, it may occur with a constricted state of the vessels, whilst, on the other, in the vessels surrounding the inflamed part, which partake of the dilated condition, the flow of blood is so far from being retarded, that it usually takes-place more rapidly than usual. But it may be fairly considered as the result of the lowered or suspended nutritive activity of the part, which will tend to retard or entirely check the motion of blood in the systemic capillaries, just as the want of aeration retards or checks the pulmonary circulation (§ 245). It is quite true that a larger amount of blood passes through a limb, of which *some part* is in a state of active inflammation, than passes through the corresponding sound limb; but this is far from indicating 'increased action' in the inflamed part, being dependent upon the augmented flow of blood through the tissues which

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* Thus Impetigo appears about blows and scratches in unhealthy children, and Erysipelas first attacks the seat of local injury in men with unhealthy blood. Perhaps as good an example as any, is afforded by the uniform limitation of the inflammation consequent upon the introduction of Vaccine matter into the blood, to the spots in which the puncture was made; notwithstanding that the whole mass of blood is affected by it, as is shown by its incapacity for subsequently developing the poison of small-pox.—See also § 210.

surround it; and if *the whole* of a limb be in a state of inflammation passing-on to gangrene (as occurs when a 'frost-bitten' limb has been incautiously warmed), the amount of blood which passes through it is diminished.—It would be just as erroneous to assume the elevated temperature of an inflamed part as a sign of 'increased action' in it; for this elevation is no doubt attributable in part to the augmented flow of blood through the surrounding vessels; and, so far as it depends upon local changes, it obviously indicates a more rapid disintegration of tissue, rather than a more energetic production of it; since it is in the former state, rather than in the latter, that the conditions of the development of heat (on the chemical theory) are supplied, as we see that the heat of a muscle is the greatest when it is being disintegrated by active exercise, not when it is being repaired by the formation of new tissue in the intervals of repose. But, as Mr. Paget justly remarks, "this phenomenon is involved in the same difficulty as are all those that concern the local variations of temperature in the body; difficulties which the doctrines of Liebig, however good for the general production of heat, are quite unable to explain." (See CHAP. X.)—And lastly, with regard to the unusual tenderness of inflamed parts, this is obviously due to such a combination of causes, neither of which can be legitimately held to indicate an increase of its proper vital activity, that nothing can be rested on this alone; especially as we see an augmentation in the susceptibility of the sentient nerves, under many circumstances (as in hysterical disorders), in which, far from an *augmented*, there is obviously a *diminished* activity in the parts from which they spring.—That neither an alteration in the circulation of a part, nor a departure from the normal condition of its nervous supply, can be regarded as one of the essential phenomena of inflammation, is obvious from this, that the most important phenomena of inflammation may present themselves, as results of injury or disease, in parts that have neither blood-vessels nor nerves: this is seen in the deposition of lymph in the cornea, in the ulceration of the cornea and of articular cartilages, and in other morbid actions in these parts, which, if ever they are vascular, become so only after the effusion of lymph in them, the new vessels being formed in this lymph, and not in the tissues themselves. Here it is obvious that the whole change consists in a perversion of the nutritive actions which the tissues ought to carry-on, at the expense of the materials which they draw from the blood of the surrounding vessels.

356. Of the alterations in the condition of the *Blood* in Inflammation, an account has already been given (§ 177); and it is here only necessary to recapitulate them. The most characteristic is the augmentation, either of the organizable or plastic fibrin, or of the organized colourless corpuscles; the increased production of these two components seeming to bear in some degree a relation of reciprocity, the one to the other. The increase of Fibrin may be considered as the alteration most characteristic of a previously-healthy and vigorous state of the system; and it is in the inflammations which occur in such subjects, that the effusions are most strongly disposed to become organized, and show the least tendency to undergo degenerative changes. On the other hand, the increase of the Corpuscular element seems to occur in cachectic or otherwise unhealthy individuals; and the inflammatory effusions which partake

of the same character, are far less plastic originally, and are extremely prone to undergo degeneration, either at the time of their effusion, or subsequently. With this increase in the proportion of fibrin and colourless corpuscles, separately or in combination, there is a diminution in the proportion of the red corpuscles, albumen, and salts of the blood. None of these changes, however, can be legitimately regarded as originally or essentially characteristic of the inflammatory condition; they are, in fact, to be looked-on rather as the results of its establishment, constituting that series of alterations in the circulating fluid, which is of parallel order to that which occurs in the solid tissues wherein the inflammatory action has been set-up.

357. The Inflammatory state is further characterized by the *effusion* and local production of certain of the components of the Blood, either upon the surface, or into the substance, of the inflamed tissues.—The effusion of pure *serum* cannot be regarded as characteristic of inflammation; since it may take-place as a mere result of congestion, especially when this congestion is due to an obstruction to the return of the blood; whilst, again, it may be due to an altered condition of the albuminous constituent of the blood, which favours its transudation (§ 173). The so-called serous effusions which are poured-forth in inflammation, do in reality contain fibrin in solution;* but this fibrin may not manifest its presence by spontaneous coagulation, until its passage into the solid state is favoured by the introduction of a piece of the washed clot of blood, or of the buffy coat, or of muscle or some other animal tissue, which seems to act as a sort of nucleus of fibrillation. The presence even of fibrin in such an effusion, however, is not in itself a sufficient proof of the existence of inflammation; for it has been shown by the experiments of Mr. Robinson,† that when the obstruction to the return of blood by the veins is so great as to occasion an excessive pressure within the capillaries, the fluid which transudes may contain enough fibrin to render it spontaneously coagulable.—The locally-developed material which is most characteristic of Inflammation, is that which is known as *coagulable lymph;* it is much to be desired, however, that some other designation should be applied to it, since the term 'lymph' can only be appropriately employed for the fluid contents of the lymphatic vessels. The peculiar characteristic of this inflammatory product, is its capability of spontaneously passing into the condition of an organized tissue, either fibrous or cellular, or a mixture of both; and of thus forming 'false membranes' on inflamed surfaces, or solidifying the inflamed part by the interstitial production of similar lowly-organized textures. Although it has been too much the habit of Pathologists, to speak of 'coagulable' or 'plastic lymph' as if it were always one and the same thing, yet it really presents various gradations of character, which are manifested in its different degrees of organizability, and in the diverse nature of the tissues developed from it; and, as Mr. Paget has pointed out,‡ there are two typical forms, the *fibrinous*, and the *corpuscular*, between which the others are intermediate. The former coagulates into a fibrous clot, resembling that of healthy blood, but usually showing a more distinct fibrillation. The latter (the 'croupous'

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* This is denied by Virchow ("Cellular Pathology," p. 392).

† "Medico-Chirurgical Transactions," vol. xxvi. p. 51.

‡ "Lectures on Surgical Pathology," vol. i. p. 332.

exudation of Rokitansky) is characterized by the want of any proper coagulation, the fibrous clot being replaced by an aggregation of cells, which in their first appearance resemble very nearly the primordial condition of the corpuscles of the fluids of the absorbent vessels, and the colourless corpuscles of the blood. It is seldom, however, that either of these typical forms of lymph presents itself in a state of complete isolation from the other; they are much more commonly blended in various proportions, so that one or the other predominates; and it is mainly upon the preponderance of fibrin, that the 'plasticity' of the fluid (or its capacity for organization) depends; whilst according to the preponderance of corpuscles, will be its tendency to degeneration. Thus the exudation of fibrinous lymph is the symbol of the 'adhesive' inflammation; whilst that of the 'corpuscular' is similarly characteristic of the 'suppurative' inflammation.

358. It is obviously of great consequence to ascertain the conditions which determine the production of one or other of these states; and these, as Mr. Paget has remarked (loc. cit.), may be considered under three heads,—(1) the previous state of the blood, (2) the seat of the inflammation, and (3) the degree and character of the inflammation. The *condition of the blood*, as determining that of the lymph, has been carefully studied by Rokitansky, who has shown that the characters of inflammatory deposits in different diatheses, correspond very generally and closely with those of the coagula found in the heart and pulmonary vessels after death. The results of Mr. Paget's experiments on the same subject have been already cited (§ 198). And clinical observation fully confirms this doctrine by evidence of another kind; that, namely, which is afforded by the different course of the same specific diseases, in different individuals, according to the previously healthy or abnormal condition of their blood. There can be no doubt that a very large proportion of what are called 'unhealthy inflammations,' especially those of the erysipelatous type, are to be regarded as owing their peculiarity to a deficiency in the due elaboration of the fibrin, and to the low vitality of the cellular components of the blood; both of which conditions seem to be favoured by the presence of those decomposing matters, whose accumulation in the blood acts in many ways so prejudicially on the system at large.*—That the quality of the local product is in some degree determined by the *seat* or *tissue* in which the Inflammation occurs, appears from the different character of the products of the disordered actions that occur simultaneously in different organs of the same individual, and apparently under the operation of the same cause; thus it may happen that in pleuro-pneumonia, the two surfaces of the pleura become connected by an organized material of a fibrous character; whilst the effusion in the substance of the lung is rather of the corpuscular nature, and speedily passes into suppurative degeneration. Mr. Paget ingeniously proposes to account for the determining influence in question, on the idea that the inflammatory product is influenced at the time of its formation by the assimilative force of each part, so that it is to be regarded as a mixture of true lymph with its special product of assimilation; thus we observe that in inflammations of bone the lymph usually ossifies, in those of liga-

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* See Mr. Brooke Gallwey's papers on 'Unhealthy Inflammation,' in the "Lancet" for 1849-50, and the "Medical Gazette" for 1850-51.

ments it is converted into a tough ligamentous tissue, and in those of secreting organs it contains a mixture of the ordinary secreted product.—The mode in which the *intensity* of the Inflammation affects the character of the effused lymph, is twofold. For, in the first place, the nature of the original effusion is likely to vary according to the degree in which the ordinary nutritive process is interrupted; since, the more intense the inflammation, the less will be the assimilating force of the part, and the more will the matters effused from the vessels deviate from the natural plasma which would be drawn from them in healthy nutrition; whilst on the other hand, when the inflammation is less severe, its product will not differ so widely from the natural one, and will from the first tend to manifest in its development some characters corresponding to those of the natural formations of the part. But, secondly, the influence of the inflammation, or rather of the depressed vitality of the inflamed tissues, is shown in the tendency to degeneration which it impresses on the locally-developed product; so that, even though this may be disposed to pass-on under favourable circumstances to the complete formation of an organized tissue, its development is early checked, and it undergoes retrograde metamorphosis; or else, from the very commencement, its development takes place according to a lower or degraded type. The normal product of the organization of either fibrinous or corpuscular lymph, is undoubtedly a tissue closely allied to the ordinary areolar or connective; it is of this that false membranes and adhesions are formed, and that the material of most thickenings and indurations of parts is composed;* and it is by the production of this tissue also, that losses of substance are in the first instance repaired, and that divided surfaces are made to adhere. Various kinds of degeneration may subsequently take place in any of these products, according to the stage at which the developmental process is checked; and among these, in tissues which have once attained an advanced stage of development, the most common is the fatty.

359. But one of the most frequent results of the inflammatory process is the formation of Pus: and the researches of Virchow and his school appear to have established that the cells which constitute so large a proportion of that fluid are not developed *de novo*, as was formerly supposed, in the fluids exuded in inflammation, but are the products of the multiplication of epithelial cells, or of the peculiar connective-tissue corpuscles, to which so much attention has recently been devoted. In the former case the puriform fluid appears as a *discharge* on the surface of the membrane, as of the Urethra in Gonorrhœa, or of the Conjunctiva in Purulent Ophthalmia; in the latter it appears in the substance and between the ultimate textural components of the tissues themselves, and then constitutes an *abscess*. When the discharge from the surface is accompanied by softening and breaking-down of the subjacent tissues, an *ulcer* is produced; but whether the disintegrating tissues are entirely removed by absorption (having previously undergone that degenerative softening which is requisite for the occurrence of this process), or

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⁂ * The Author is much disposed, however, to agree with Dr. Handfield Jones, in believing that a chronic 'fibroid degeneration,' resulting from the substitution of a lowly-organized fibrous tissue for the proper texture of the part, may take place, like 'tubercular degeneration' (§ 360), without the occurrence of Inflammation, properly so called. See "Brit. and For. Med.-Chir. Rev.," vol. xiii. pp. 343-349.

whether they are broken-up and dissolved in the purulent fluid, is a point not yet determined. The *conservative* nature of the fibrinous exudation, and the consequent importance of fibrin as an element of it, are well shown by the results of its deficiency. Thus if there be no 'sac' formed around a collection of pus, this fluid infiltrates through the tissues, and by its mere presence so impairs their nutrition, that a corresponding degradation takes place in the characters of the plastic material furnished for their assimilation; and hence the purulent effusion spreads without limit, and the tissues through which it percolates undergo rapid degeneration. So, again, when gangrene is spreading by contiguity (the proximity of the dead tissue tending to lower the vitality, and even to occasion the death, of that with which it is continuous), it is only when an inflammatory 'reaction' occurs, or, in other words, when a development of fibrinous lymph takes place in the substance of the tissues bordering on those which have lost their vitality, that a line of demarcation between the dead and the living parts is formed. And generally it may be said, that, as the ultimate tendency of Inflammation is to produce the disintegration of the part, the ultimate tendency of the fibrinous material developed is to keep its elements together, and to repair the losses which have taken place, although with a very inferior material.—It is only, however, with the subsidence of the inflammation, and the return to the ordinary type of nutrition, that the highest development of the lymph can take place; and it is in proportion as this occurs more speedily, that the recovery of the organization proper to the part is more completely effected.*

360. In persons of that peculiar constitution, which is termed *Scrofulous* or *Strumous*, we find an imperfectly-organizable or *cacoplastic* deposit, or even an altogether *aplastic* product, known by the designation of *Tubercular* matter, frequently taking the place of the normal elements of tissue; both in the ordinary process of Nutrition, and still more when Inflammation is set-up. From an examination of the Blood of tuberculous subjects, it appears that although the bulk of the coagulum obtained by stirring or beating it is usually greater than that of healthy blood, yet this coagulum is not composed of well-elaborated Fibrin; for it is soft and loose, and contains an unusually-large number of Colourless corpuscles, whilst the Red corpuscles form an abnormally-small proportion of it. We can understand, therefore, that such a constant deficiency in plasticity must affect the ordinary nutritive process; and that there will be a liability to the deposit of cacoplastic products, instead of the normal elements of tissue, even without inflammation. Such appears to

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* The Author has pleasure in referring to Mr. Paget's "Lectures on Surgical Pathology" (vol. i.), as containing, in his opinion, the best exposition of the subject of Inflammation yet made public; and in acknowledging his obligations to them for much assistance in the short view of it given above.—The fundamental doctrines on which the Author would lay the greatest stress, however, are the same in all essential particulars with those which he taught in the earlier editions of this Treatise. An excellent account of the general phenomena and pathology of Inflammation has been written by Mr. Simon in "Holmes's System of Surgery," vol. i. p. i. The interesting paper of Mr. Lister 'On the Early Stages of Inflammation,' in the "Philosophical Transactions for 1858," will also well repay perusal. The work of Virchow, "Cellular Pathology," translated by Dr. Chance, contains a full account of the peculiar and now very generally-received views of this author on the pathology of Inflammation. (See chap. viii. and xvii.)

be the history of the formation of Tubercles in the lungs and other organs, when it occurs as a kind of metamorphosis of the ordinary Nutritive process; and in this manner it may proceed insidiously for a long period, so that a large part of the tissue of the lungs shall be replaced by tubercular deposit, without any other ostensible sign than an increasing difficulty of respiration. In the different forms of tubercular deposit, we see the gradation most strikingly displayed between the plastic and the aplastic formations. In the semi-transparent, miliary, grey, and tough yellow forms of Tubercle, we find traces of organization in the form of cells and fibres, more or less obvious; these being sometimes almost as perfectly formed as those of plastic lymph, at least on the superficial part of the deposit, which is in immediate relation with the living structures around; whilst they may be so degenerated, as scarcely to be distinguishable. In no instances do such deposits ever undergo further organization; and therefore they must be regarded as *cacoplastic.* But in the opaque, crude, or yellow Tubercle, we do not find even these traces of definite structure; for the matter of which it consists is altogether granular, more resembling that which we find in an albuminous coagulum. This is entirely *aplastic.* Yet there is every probability, as Virchow has shown,* that at an early period this also consisted of, or contained, numerous nuclei and small uni- or multi-nucleated cells, developed as the result of an inflammatory process from the proliferation of connective-tissue corpuscles, and undergoing fatty degeneration and subsequent shrivelling at a very early period. The larger the proportion of this kind of matter in a tubercular deposit, the more is it prone to *soften;* whilst the semi-organized tubercle has more tendency to *contraction.*—Thus it may now be held as established with certainty that Tubercular matter is always, even in its most amorphous state, a product of cell-formation; and that the difference between the amount of organization which its several forms present, is due rather to a variation in the degree of its subsequent degeneration, than to an original diversity in histological condition.†

361. But although Tubercular matter may be slowly and insidiously deposited, by a kind of degradation of the ordinary Nutritive process, yet it cannot be doubted that Inflammation has a great tendency to favour it; so that a larger quantity may be produced in the lungs, after a Pneumonia has existed for a day or two, than it would have required years to generate in the previous mode. But the character of the deposit still remains the same; and its relation to the plastic element of the blood is shown by the interesting fact, of no unfrequent occurrence,—that, in a Pneumonia affecting a tuberculous subject, plastic lymph is often thrown out in one part, whilst tubercular matter is deposited in another. Now Inflammation, producing a rapid deposition of tubercular matter, is peculiarly liable to arise in organs which have been previously affected with chronic tubercular deposits by an impairment of the process of textural Nutrition; for these deposits, acting like foreign bodies, may of themselves become sources of irritation; and the perversion of the structure

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* Loc. cit., p. 476.

† See Mr. Paget in the "Pathological Catalogue of the Hunterian Museum," vol. i. p. 134; also Dr. Madden's "Thoughts on Pulmonary Consumption."

and functions of the part renders it peculiarly susceptible of the influence of external morbific causes.

362. We frequently meet with abnormal growths of a Fatty, Cartilaginous, Fibrous, or even Bony structure; which result from the development of these tissues in unusual situations, and appear to originate in some perverted action of the parts themselves (§§ 337, 358 *note*).—But there is another remarkable form of disordered Nutrition, which is concerned in producing what have been termed *heterologous* growths; that is, masses of tissue that differ in character from any which is normally present in the body. Most of these are included under the general designation of *Cancerous* or *Fungous* structures; and it has been shown by Muller and succeeding inquirers, that the new growth consists of a mass of cells; which, like the Vegetable Fungi, develope themselves with great rapidity; and which destroy the surrounding tissues by their pressure, as well as by abstracting from the Blood the nourishment which was destined for them. These parasitic masses have a completely independent power of growth and reproduction; and some kinds of them can be propagated by inoculation, which conveys into the tissues of the animal operated-on, the germs of the peculiar cells that constitute the morbid growth, these soon developing themselves into a new mass. So it may be by the diffusion of the germs produced in one part, through the whole fabric, by means of the circulating current, that the tendency to re-appearance (which is one great feature in the *malignant* character of these diseases) is occasioned. But it would seem more probable, that this character rather depends upon the presence of a morbid matter in the blood, of which the formation of the Cancerous tissue is only the manifestation (§ 312 *note*); the local disease thus being the consequence of a constitutional cachexia, rather than the constitutional affection the result of the local disease.*

CHAPTER IX.

OF SECRETION AND EXCRETION.

1. *Of Secretion in General.*

363. The literal meaning of the term Secretion is *separation;* and this is nearly its true acceptation in Physiology. But the ordinary processes of Nutrition involve a separation of certain of the components of the Blood, which are withdrawn from it by the appropriating power of the solid textures; and every such removal may be considered in the light of an act of *excretion*, so far as the blood and the rest of the organism are concerned (§ 199). Moreover, the separation of certain matters from the blood in a fluid state, either for the purpose of being cast-forth from the

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* See Dr. Walshe on "The Nature and Treatment of Cancer;" Mr. Simon's "General Pathology," Lect. viii.; and Mr. Paget's "Lectures on Surgical Pathology," vol. ii. Lect. xiv.

body, or of being employed for some special purpose within it, which constitutes what is ordinarily known as Secretion, is effected by an instrumentality of the same nature with that whose operation constitutes an essential part of the nutritive process; namely, the production and subsequent agency of cells. Hence there is no other fundamental difference between the two processes, than such as arises out of the diverse *destinations* of the separated matters, and from the anatomical arrangements which respectively minister to these. For the products of the Secreting action are all poured-forth, either upon the external surface of the body, or upon the lining of some of the cavities which communicate with it; and the cells by which they are separated from the blood, usually stand in the relation of epithelium-cells to those prolongations of the skin or of mucous membranes, that form the follicles or extended tubuli of which the Glandular organs are for the most part composed (Figs. 74, 81). The act of Secretion appears to consist, in some cases, in the successive production and exuviation of the cells which minister to it, these cells giving-up, by rupture or deliquescence, the substances which they have eliminated from the blood; such, for example, appears to be the mode of separation of the Sebaceous secretion of the skin, of the Mucous secretion of mucous membranes, of the secretion of Milk, and perhaps also of the Biliary secretion. On the other hand, there can be little question that those more liquid secretions, in which there is either very little solid matter (as is the case with the Cutaneous transpiration and the Lachrymal fluid), or in which the solids, though in larger amount, are in a state of such perfect solution as to be capable of easy transudation (as is the case with the Urine), are not formed in this mode; since neither are exuviated cells normally found in the secreted fluids, nor do the epithelial cells lining the glandular tubes or follicles present indications of being in a state of continual change. Still, even in these cases, it seems fair to conclude that the *selective* powers of the gland-cells are employed in drawing from the blood, on one side, the special products which are to be set-free by transudation on the other. Each group of cells is thus adapted to separate a product of some particular kind, which constitutes its special *pabulum;* and the rate of its production seems to depend, *cæteris paribus*, upon the amount of that pabulum supplied by the circulating fluid. The substances at the expense of which the secreting cells grow, however, may not be precisely those which are subsequently cast-forth; for it is very probable that some of them, at least, undergo a certain degree of chemical transformation by the agency of these cells; the characteristic materials of the several secretions not being always found to pre-exist *as such* in the blood.

364. A distinction may be drawn as regards this point, between those *Excretions*, the retention of whose materials in the Blood would be positively injurious, and those *Secretions*, which are destined for particular purposes within the system, and the suspension of which has no immediate influence on any other functions than those for which they are respectively destined. The solid matter dissolved in the fluids of the latter class, is little else than a portion of the *nutritive* constituents of the Blood; either so little altered as still to retain its nutritive character, as is the case with the casein of Milk, and with the albuminous constituent of the Serous fluid of areolar tissue and of serous and synovial membranes; or

in a state of incipient retrograde metamorphosis, as seems to be the case with the peculiar 'ferments' of the salivary, gastric, pancreatic, and intestinal secretions. On the other hand, the characteristic ingredients of the Excretions are very different in character from the normal elements of the blood. They are all of them completely unorganizable; and they possess, for the most part, a simple atomic constitution. Some of them also, have a tendency to assume a crystalline form; which, as Dr. Prout justly remarked, indicates their unfitness to enter into the composition of organized tissues. With regard to some of the chief of these, there is sufficient evidence of their existence, in small quantity, in the circulating Blood; but it is also clear that they exist there as products of decomposition, and that they are destined to be separated from it as speedily as possible. If their separation be prevented, they accumulate, and communicate to the circulating fluid a positively deleterious character. Of this, we have already seen a striking example in the case of Asphyxia (§ 299); and the history of the other two principal excretions, the Bile and Urine, will furnish evidence to the same effect.—As a general fact, then, it may be affirmed, that the materials of the proper Excretions pre-exist in the Blood, in a state nearly resembling that in which they are thrown-off by the secreting organs; and that, as their presence there is the result of the destructive changes that have taken place in the system, they cannot be retained in it without injury: but that the materials of those Secretions which are destined to perform some particular function within the economy, are derived from the nutritive substances which are appropriated to its general purposes.

365. Notwithstanding that, under ordinary circumstances, the several parts of the Excretory apparatus are limited, each to its own special function, we find that there are certain *complementary* relations between them, which make the action of one vicarious to a certain extent with that of another. Such a relation seems to exist, for instance, between the Lungs on one side, and the Liver and Intestinal glandulæ on the other; for, the more active the respiration, the less bile is secreted; whilst, if the respiration be lowered in amount by inactivity of body and a high external temperature, a larger proportion of unoxidized or imperfectly-oxidized excrementitious matters accumulates in the blood, giving rise to that augmented production both of the biliary and of the fæcal excretions, which constitutes diarrhœa.* And thus, on the other hand, when the liver is not adequately effecting the depuration of the blood from the constituents of bile, an augmentation of the respiration by active exercise in a low temperature gives most effectual relief.—Still more obviously vicarious, however, are the Kidneys and the Skin; for here we find that not only do the kidneys allow the transudation of whatever superfluous water may remain in the circulating current, after a sufficient amount has been exhaled from the skin to keep-down the temperature of the body to its normal standard, but the skin actually assists in the elimination of one of those products of the metamorphosis of the azotized tissues, the removal of which has been until recently consi-

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* Such is probably the occasion of the 'bilious attacks' and 'autumnal cholera' so prevalent at the close of the summer; the subjects of these being most commonly persons who have not reduced their consumption of food during the warm season, in accordance with the diminished demand for the production of heat within the body.

dered as the special function of the kidney. Consequently, whenever the due action of the skin as an excreting organ is interfered-with, it is the kidney especially that will be called-on to take its place; whilst, on the other hand, if it be thought desirable to relieve the kidney, this may be most effectually done by stimulating the skin to increased excretory activity.—This vicariousness of function among the Excretory organs presents itself far more remarkably, however, in certain states of disease; in which a complete 'metastasis of secretion' may exhibit itself. The capability of one organ thus to take upon itself the special action of another, appears to be related to the 'community of function' existing in the secretory surface among those lower animals, which manifest none of the 'specialization' or setting-apart for particular offices, that we see in the higher; for it seems to be a general law in Physiology, that, even where the different functions are most highly specialized, the general structure retains, more or less, that primitive community of action which characterized it in the lowest grade of development.*

366. It is in regard to the *Urinary* excretion, that the evidence on this point is most complete; for it seems to be established by a great mass of observations, that urine, or a fluid presenting its essential characters, may pass-off by the mucous membrane of the intestinal canal, by the salivary, lachrymal, and mammary glands, by the testes, by the ears, nose, and navel, by parts of the ordinary cutaneous surface, and even by serous membranes, such as the arachnoid tunic lining the ventricles of the brain, the pleura, and the peritoneum. A considerable number of such cases was collected by Haller:† many more were brought-together by Nysten;‡ more recently Burdach has furnished a full summary of the most important phenomena of the kind;§ and Dr. Laycock has compiled a valuable collection of cases of urinary metastasis occurring as complications of hysteria.‖ The following table of cases referred-to by the last of these authors, will give some idea of the relative frequency of the different forms of this curious affection:—

Vomit.	Stool.	Ears.	Eyes.	Saliva.	Nose.	Mammæ.	Navel.	Skin.	Total.
34	20	4	4	5	3	4	34	17	125

It is to be borne in mind, however, that cases of hysterical ischuria are frequently complicated with that strange moral perversion, which leads to the most persevering and ingenious attempts at deceit; and there can be little doubt that a good many of the instances on record, especially of urinous vomiting, are by no means veritable examples of metastasis.—The proofs of the fact we are seeking to establish are, therefore, much more satisfactory when drawn from experiments upon animals, or from pathological observations, about which, from their very nature, there can be no mistake. Thus Mayer¶ found that when the two kidneys were extirpated in the guinea-pig, the cavities of the peritoneum and the pleura, the ventricles of the brain, the stomach, and the intestinal canal, contained a brownish liquid having the odour of urine; that the tears exhaled the same odour; that the gall-bladder contained a brownish liquid not resembling bile; and that the testes, the epididymis, the vasa deferentia, and the vesiculæ seminales, were gorged with a liquid perfectly similar to urine. Chirac and Helvetius are quoted by Haller as having tied the renal arteries in dogs, and having then remarked that a urinous fluid was passed-off from the stomach by vomiting. A remarkable case is quoted by Nysten from Zeviani, in which a young woman having received an incised wound on the external genitals, which would not heal, the urine gradually became more scanty, until none could be passed even with the assistance of the catheter; at last dropsy supervened, with sweats of a urinous odour, and vomiting of a urinous fluid, which continued daily for thirty-three years: on post-mortem examination, the kidneys were found disorganized, the right ureter entirely obliterated and the left nearly so, and the bladder contracted to the size of a pigeon's egg.—In some other instances, the urine appears to have been secreted, and then re-absorbed in consequence of some obstruction to its exit through the urinary passages. Thus Nysten quotes a case from Wrisberg, in which, the urethra having been partially obstructed for ten years by an enlarged prostate, the bladder was so distended as to contain ten pounds of urine; and the serosity of the pericardium and of the ventricles of the brain exhaled a urinous odour. He cites other instances, in which the presence of calculi in the bladder prevented the due discharge of the secretion; and in which a urinous liquid was ejected from the stomach by vomiting, or was discharged by stool. A still more remarkable case is recorded, of a girl born without either anus or external genitals, who nevertheless remained in good health to the age of fifteen years, passing her urine from the nipples, and getting rid of fæcal matters by vomiting.—There are cases, moreover, in which it would seem that the mucous lining of the urinary bladder must have had a special power of secreting urine; the usual discharge having taken place to the end of life, when, as appeared by post-mortem examination, the kidneys were so completely disorganized that they could not have furnished it, or had been prevented by original malformation, or by ligature of the urethra, from discharging it into the bladder. A considerable number of these have been collected by Burdach.* In all the older statements of this kind, there is a deficiency of evidence that the fluids were really urinous, urea not having been obtained from them by chemical analysis, and the smell having been chiefly relied-on. The urinous odour, however, when distinct, is probably nearly as good an indication of the presence of the most characteristic constituent of human urine, as is the appearance of the urea in its separated form. The passage of a urinous fluid from the skin has been frequently observed in cases in which the renal secretion was scanty; and the critical sweats, by which attacks of gout sometimes terminate, contain urates and phosphates in such abundance as to form a powdery deposit on the surface.

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* See "Princ. of Comp. Phys.," §§ 110, 428.

† "Elementa Physiologiæ," tom. ii. p. 370.

‡ "Recherches de Physiologie et de Chimie pathologiques," p. 265.

§ "Traité de Physiologie" (Jourdan's Translation), vol. viii. p. 248 *et seq.*

‖ "Edinb. Med. and Surg. Journ.," 1838; and "Nervous Diseases of Women," p. 233.

¶ "Zeitschrift für Physiologie," tom. ii. p. 270.

367. The metastasis of the *Biliary* secretion is familiar to every prac-

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* "Zeitschrift für Physiologie," tom. ii. pp. 253, 254.

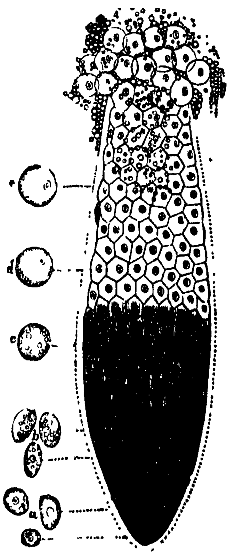
titioner, as being the change on which *jaundice* is dependent. It is not, however, in every case of yellowish-brown discoloration of the tissues, that we are to impute such discoloration to the presence of biliary matter; and we can only safely do so, when we have at the same time evidence of concurrent obstruction of the biliary apparatus. The urinary apparatus then affords the principal channel through which the biliary matter is eliminated; the urine becomes tinged with the colouring principle of bile, being sometimes of a yellowish or orange hue, and sometimes of a brown colour with a considerable sediment; and the presence of the most characteristic constituents of the bile has been determined in the urine. The same result presents itself, when the biliary duct has been artificially obstructed by ligature. Other secretions have been found tinged with the colouring matter of bile: thus the pancreatic fluid has been seen of a yellow colour in jaundice; and the milk has presented not merely the hue, but the characteristic bitterness, of the biliary secretion. The cutaneous transpiration is not unfrequently so much impregnated with biliary matter, as to communicate its tinge to the linen covering the skin; and even the sputa of patients affected with bilious fevers have been observed to be similarly coloured, and have been found to contain biliary matter. The secretions of serous membranes, also, have been frequently seen to present the characteristic hue of bile; and biliary matter has been detected, by analysis, in the fluid of the pleural and peritoneal cavities. Biliary matter, however, when unduly present in the circulating current, is not removed from it by the secreting organs alone; for it seems to be withdrawn also in the ordinary operations of nutrition, entering into combination with the solid tissues. Thus, in persons affected with jaundice, we find the skin, the mucous and serous membranes, the lymphatic glands, the brain, the fibrous tissues, the cartilages, the bones and teeth, and even the hair, penetrated with the colouring matter of the bile, which they must have withdrawn from the blood, and which seems to have a particular affinity for the gelatinous tissues. It is impossible at present to say, however, to what extent the more characteristic ingredients of the bile are thus withdrawn from the blood; for the presence of its *colouring matter* cannot by any means be taken as an indication, that its peculiar *resinoid acids* are also incorporated with the normal components of the tissues.

2. *The Liver.—Secretion of Bile.*

368. The *Liver* is probably more constantly present, under some form or other, throughout the entire Animal series, than any other gland. Its form and condition vary so greatly, however, in different tribes, that, without a knowledge of its essential structure, we should be disposed to question whether any identity of character exists among the several organs which are regarded as Hepatic. It is, in fact, the presence of bile-secreting cells, that must be held to constitute a Liver; and these may be scattered over the general lining membrane of the alimentary canal, or may be restricted within follicles which are formed by depressions of it; these follicles, again, may be multiplied in some particular spot, so as to be aggregated into a mass, or may be extended into long tubes. In all the Invertebrata, however, the Liver is obviously conformable to the

general type of glandular structures; the hepatic cells being in immediate relation with a basement-membrane, and being discharged upon a free surface. This will be readily understood from an examination of any one of the higher forms of it, such as that presented in the liver of the Crab, which, like the liver of the Mollusca generally, is a lobulated glandular mass, formed by the aggregation of a multitude of follicles with distinct cæcal terminations; these follicles discharging their secreted products into cavities which occupy the centre of the lobules, whence they are collected by the ducts which convey them into the alimentary canal. On a careful examination of these follicles (Fig. 74), and a comparison of the size and contents of the cells at the bottom and towards the outlet, it becomes evident that the cells originate in the former situation, and gradually increase in size as they advance towards the latter. It is also to be observed that the cells which lie deepest in the cæcum (*a*, *b*), contain for the most part the yellow granular matter, which may be regarded as the proper biliary secretion; but as they increase in size, there is also an increase in the quantity of oil-globules which they contain (*c*), until past the middle of the follicle, where they are found full of oil, so as to have the appearance of ordinary fat-cells (*d*, *e*). From this it happens, that when an entire cæcum is examined microscopically, its lower half appears filled with a finely-granular matter, intermingled with nucleated particles; and the upper half with a mass of fat-cells, whose nuclei are obscured by the oily particles.*—In Vertebrated animals, the Liver seems to be constructed upon a similar plan. Its component cells are still contained in distinct cæcal follicles or elongated tubuli branching-off from the excretory ducts; but in ascending through the Vertebrated series, it presents a more and more solid parenchymatous texture, which strikingly contrasts with its loosely-lobulated racemose aspect in even the highest Invertebrata. This character is very obvious in the liver of Man, which is peculiarly firm and compact, and has less of connective tissue between its different parts than is found in that of many other Mammalia.—It is observable, moreover, in the Human liver, that certain portions are rudimentary, which are elsewhere fully developed. Thus in the Carnivora and Rodentia, which present the most complex form of liver that we meet-with among Mammalia, there are five distinct parts; namely, a 'central' or principal lobe, and a right and left 'lateral' lobe, each with its 'lobular appendage.' The whole mass of the liver of Man,

FIG. 74.



One of the Hepatic cæca of *Astacus affinis* (Cray-fish), highly magnified, showing the progress of development of the secreting cells from the blind extremity to the mouth of the follicle; specimens of these, in their successive stages, are shown separately at *a, b, c, d, e*.

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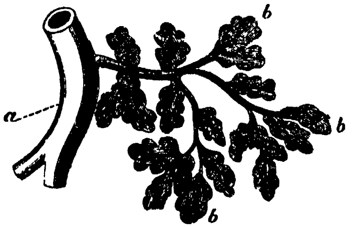
* See Dr. Leidy's 'Researches into the Comparative Structure of the Liver,' in "Amer. Journ. of Med. Sci.," Jan. 1848.

which we are accustomed to describe as consisting of a 'right' and 'left' lobe, does in reality form but one (there being no real division between its two portions), which must be regarded as the 'central' lobe; the 'lobulus Spigelii' is the rudiment of a right 'lateral' lobe, and the 'lobulus caudatus' is its 'lobular appendage;' but the left 'lateral' lobe, with its 'lobular appendage,' is altogether undeveloped.*

369. When the Liver is closely examined with the naked eye, it is seen to be made-up of a great number of small granular bodies, about the size of millet-seeds, of an irregular form, and presenting a number of rounded projecting processes upon their surfaces. These are commonly termed *lobules*, although by some Anatomists they are spoken-of as *acini*.† When divided longitudinally, they have a somewhat foliated appearance (Fig. 75), arising from the distribution of the Hepatic Vein, which passes into the centre of each division. When transversely divided, the lobules are usually found to present somewhat of a pentagonal or a hexagonal shape, the angles being slightly rounded, so as to form a series of passages or interlobular spaces: in these lie the branches of the Vena Portæ (as well as of the Hepatic Artery and Duct), from which are derived the plexuses that enter the lobules. The exterior of each lobule is covered by a process of the 'capsule of Glisson,' which is very dense in the Pig and other animals, but is so thin as to be almost undistinguishable in the Human liver; the interspaces between the vessels are filled by the ultimate terminations of the Hepatic biliary ducts, which contain large secreting cells.‡ The structure of each lobule, then, gives us the essential characters of the whole gland.

FIG. 75.



Connection of the *Lobules of the Liver* with the Hepatic Vein;—*a*, trunk of the vein; *b*, *b*, lobules depending from its branches, like leaves on a tree; the centre of each being occupied by a venous twig, the Intralobular Vein.

370. The *Vena Portæ*, which is formed by the convergence of the veins that return the blood from the chylopoietic viscera, probably also receives the blood which is conveyed to the liver for the purposes of nutrition by the Hepatic Artery. Like an artery, it gradually subdivides into smaller and yet smaller branches; and at last it forms a plexus of vessels, which lie in the interlobular spaces, and spread with the freest inosculation throughout the entire Liver. To these vessels, the name of *interlobular* Veins was given by Mr. Kiernan.§ They ramify in the capsules

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* For a general view of the Comparative Structure of the Liver in different classes of animals, see "Princ. of Comp. Phys.," §§ 405-411.

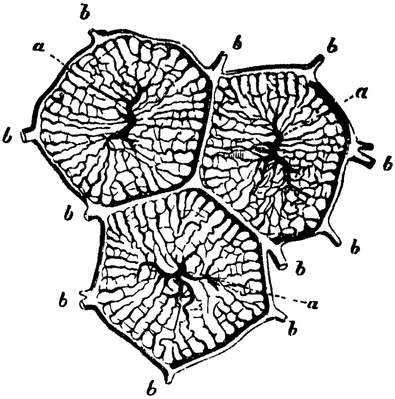
† The *acini* of Malpighi are the minute bodies of various forms and yellowish colour, which are seen when any individual lobule is examined with the microscope; these are nothing else, however, than the irregular islets of parenchyma, left between the meshes of the plexus formed by the ultimate ramifications of the portal vein.

‡ See Prof. Beale's Paper 'On the Ultimate Arrangement of the Biliary Ducts,' in "Phil. Trans.," 1856, and Todd and Bowman's "Physiolog. Anat.," p. 459, vol. ii. 1859.

§ See his admirable Memoir 'On the Anatomy and Physiology of the Liver,' in the "Philosophical Transactions," 1833.

of the lobules, covering with their ramifications the whole external surface of these; and then enter their substance. When they enter the lobules, they are termed *lobular* veins; and the plexus formed by their convergence from the circumference of each lobule towards its centre (where their ultimate ramifications terminate in those of the intralobular or hepatic vein), is designated as the *lobular venous plexus.*—The *Hepatic Artery* sends branches to every part of the Liver, supplying the walls of the portal and hepatic veins, and of the hepatic ducts, as well as Glisson's capsule. The principal distribution of its branches, however, is to the lobules; which they reach, in the same manner with the portal vessels and biliary ducts, by spreading themselves through the interlobular spaces. There they ramify upon the interlobular ducts, and upon the capsular surface of the lobules, which they then penetrate; terminating for the most part in the portal venous plexus, though a very few small branches may be traced into the Hepatic plexus of capillaries. The whole of the blood, therefore, of the Hepatic Artery passes through the lobuli, and is subservient to

FIG. 76.



Horizontal section of three superficial Lobules, showing the two principal systems of *Blood-vessels*; —*a*, *a*, *intra*-lobular veins, terminating in the Hepatic veins; *b*, *b*, *inter*-lobular plexus, formed by branches of the Portal vein.

FIG. 77.

Section of a small portion of the *Liver* of a *Rabbit*, with the Hepatic or intralobular veins injected.

the secretion of Bile.—It now only remains to describe the *Hepatic Veins*, the branches of which occupy the interior of the lobules, and are termed *intra*lobular veins (Fig. 76, *a*, *a*, Fig. 77). On making a transverse section of a lobule, it is seen that the central vessel is formed by the convergence of numerous minute venules, which arise from the plexus upon the surface*of the lobule. The intralobular veins terminate in the larger trunks, which pass along the bases of the lobules, collecting from them their venous blood; these are called by Mr. Kiernan *sub-lobular* veins. The main trunk of the Hepatic Vein terminates in the ascending Vena Cava.

371. The *Hepatic Duct* forms, by its subdivision and ramification, an interlobular plexus very like that of the portal vein; the branches ramifying upon the capsular surface of the lobules, and ultimately penetrating into their interior. At the point where the interlobular ducts become continuous with the cell-containing network within the lobules, their diameter is very small, not exceeding 1-4000th to 1-5000th of an inch; and here the epithelium, which in the larger ducts is columnar, passing in the smaller ducts into the tesselated variety, suddenly becomes spheroidal, or assumes the form of the true secreting cell. The tubes, of the diameter of 1-80th of an inch and larger, present many little saccular dilatations of the coats, the openings of which, according to Dr. Beale, are regularly arranged in two rows or lines on opposite sides of the ducts; and besides these are numerous small, irregular, and anastomosing canals, which run obliquely in the coats of the ducts, and ultimately open into their cavities. These tubes and cæca may be regarded as accessory gall-bladders, in which the Bile, secreted and stored-up, comes into intimate relation with a fine plexus of capillaries, and may perhaps undergo further elaboration.

FIG. 78.*

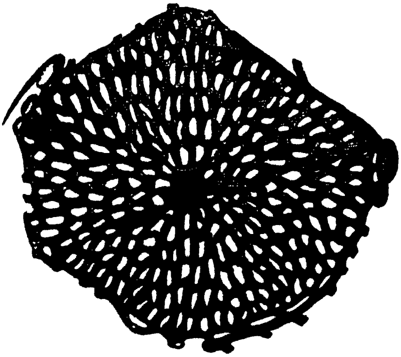
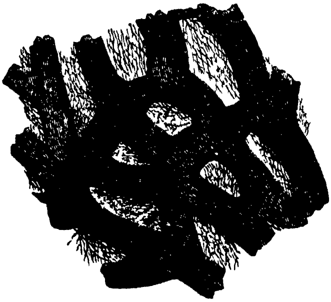


FIG. 79.†



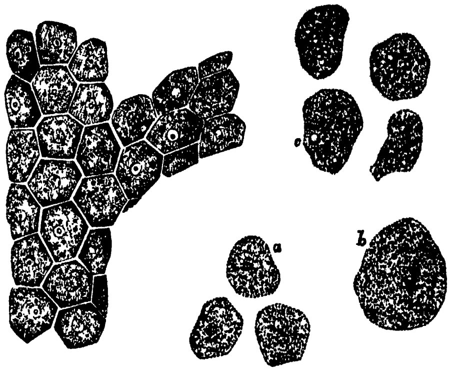
* Transverse section of a *Lobule* of the Human Liver, showing the reticular arrangement of its parenchyma, with some of the branches of the Hepatic Vein in the centre, and those of the Portal Vein at the periphery.

† A small portion of this section more highly magnified, showing the columns of secreting cells of which the parenchyma is composed.

372. The substance of each lobule may be considered as a close *network* of hepatic tubes (Figs. 78, 79); the interspaces of which are so completely occupied by the vascular network already described, that, when the latter is fully injected, no vacuities are seen. The meshes of the parenchymatous network have a more rounded form towards the margin of the

lobule, whilst in the centre they are disposed more radially; so that in a section cutting the intralobular vein transversely, long branching columns of hepatic cells are seen stretching from the latter on all sides, and uniting by short lateral anastomoses (as in Fig. 79), so that the intermediate meshes appear like narrow elongated clefts. These columns (Fig. 80, A) usually consist of from three to five rows of cells, and are almost always to be found among scraped-off particles of the liver.

FIG. 80.



A, portion of a *Hepatic Column*, from Human Liver, showing its component secreting cells:—B, secreting cells detached, *a*, in their normal state, *b*, a cell more highly magnified, showing the nucleus and distinct oil-particles, *c*, in various stages of fatty degeneration.

373. The *biliary cells* of the Human liver (Fig. 80, B) are usually of a flattened spheroidal form, and from 1-500th to 1-2000th of an inch in diameter. Each of them presents a distinct nucleus; and the cavity of the cell is occupied by yellow amorphous biliary matter, usually having one or two large adipose globules, or five or six small ones, intermingled with it (*a*, *b*). The size and number of these, however, vary considerably, according to the nature of the food, the amount of exercise recently taken, and other circumstances. If an animal be very fat or be well fed, especially with farinaceous or oleaginous substances, the proportion of adipose particles (*c*) is much greater than in an animal moderately fed and taking much exercise. The size of the oil-globules varies from that of mere points, scarcely distinguishable from the granular contents of the cells except by their intense blackness, up to one-fourth of the diameter of the cell. A still greater accumulation of adipose particles in the biliary cells, gives rise, as was first pointed-out by Mr. Bowman,* to the peculiar condition termed 'fatty liver.' The finely-granular matter is the portion from which the colour of the cell is derived; it seems to fill the space not occupied by the oil-globules; and it often obscures the nucleus, so that the latter cannot be distinguished until acetic acid is added, which makes the granular matter more transparent without affecting the nucleus.—The Liver, therefore, belongs to the class of ramified tubular glands; and the materials of the biliary secretion formed from the blood by the cells lining the intralobular extremities of the ducts are discharged into the interior of these canals either by exudation or by the deliquescence of the cells themselves. Teichmann† has traced the lymphatics running with the portal venous branches and the biliary ducts to form a plexus with large, irregular meshes on the outside of the lobuli, and he believes he has even injected minute branches passing up

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* "Medical Gazette," Jan. 1842. † "Saugader System," p. 94, Leipzig, 1861.

centre with the Vena intralobularis of the Hepatic Veins. There is also a single layer of lymphatics on the peritoneal surface of the Liver, lying in the subserous areolar tissue. The nerves of the Liver have been carefully examined by Dr. Robert Lee,[*] and shown to be chiefly connected with the semilunar ganglion and sympathetic plexus surrounding the root of the hepatic artery, the minutest branches of which they accompany.

374. The first and most obvious function performed by the Liver is the secretion of Bile. For this the arrangement of the cells and ducts appears to be primarily designed; and by their means a considerable quantity of material rich in carbon and hydrogen is, temporarily at least, eliminated from the blood, whilst at the same time a liquid is provided, the utility of which in promoting the absorption of food has been already sufficiently considered (§ 96). But the large size of this organ in comparison with the amount of secretion poured into the alimentary canal; its constant presence in almost all classes of animals, how various soever the nature of their food may be; its manifest activity in the fœtus before the ingestion of any food has taken place; the large supply of blood which it receives from different sources, as well as the peculiar relations which it holds to the blood returning from the placenta in the fœtus, and from the abdominal viscera in the adult—are all circumstances suggesting that other functions than the secretion of the Bile are here performed; and from the results of comparatively recent research, it may now be considered as fairly established, that it exerts an assimilative or elaborating action on the freshly-absorbed materials of our food, and especially upon the albuminous and saccharine constituents, whereby they become more fitted for the nutrition of the body; and that in the course of these assimilative changes, the activity of which is indicated by the high temperature of the organ, and perhaps as a consequence of them, a material analogous to sugar is formed, whose ultimate destination is still undetermined, but which, there is strong reason for believing, either directly or indirectly combines with oxygen, and thus becomes subservient to the maintenance of animal heat. The production of this substance is termed Glycogeny, and will be considered after the characters and mode of formation of the Bile have been discussed. The following are analyses of the Bile contained in the human Gall-bladder, by Frerichs and v. Gorup-Besanez:[†]—

In 1000 parts.	FRERICHS.		V. GORUP-BESANEZ.			
	I. Man æt. 18, killed by a fall.	II. Man æt. 22, killed by injury.	I. Man æt. 49, criminal beheaded.	II. Woman æt. 29, criminal beheaded.	III. Man æt. 68, killed by a fall.	IV. Boy æt. 12, killed by an injury.
Water	860·0	859·2	822·7	898·1	908·7	828·1
Solid residue . . .	140·0	140·8	177·3	101·9	91·3	171·9
Biliary acids in combination with alkalies	72·2	91·4	107·9	56·5	73·7	148·0
Fat	3·2	9·2	47·3	30·9		
Cholesterin . . .	1·6	2·6				
Mucus and colouring matter.	26·6	29·8	22·1	14·5	17·6	23·9
Salts.	6·5	7·7	10·8	6·3	—	—

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[*] "Proceedings of Royal Society," vol. xii. p. 246.

[†] "Phys. Chem.," 1862, p. 469.

Bile is a viscid, neutral or feebly-alkaline, somewhat oily-looking liquid, of a greenish-yellow colour, and very bitter taste, followed by a sweetish after-taste. It is readily miscible with water, and its solution froths like one of soap. Its specific gravity in the human subject is about 1018. The proportion of solid matter which it contains is usually from 9 to 17 per cent, and nearly the whole of this consists of substances peculiar to Bile. In the Biliary matter, according to the researches of Strecker (which are undoubtedly the most accurate and satisfactory that have been hitherto made), the following substances may be distinguished:—Two resinous acids, the *Glycocholic* (which is the *cholic* of Strecker and many former authors) and the *Taurocholic* (which is the *choleic* acid of Strecker, and is nearly the same with the bilin of other chemists); these are formed, according to Lehmann, by the 'conjugation' of Cholic acid with glycine (gelatine-sugar) and taurine respectively; and they are united in the bile with soda as a base. It is in the taurocholic acid that the sulphur of the bile presents itself, no less than 25 per cent of that element existing in taurine; so that the proportion which this acid bears to the glycocholic (which differs greatly in different animals) may be estimated by the amount of sulphur in the mixture of the two.[*] Besides a variable quantity of the ordinary Fatty acids, Bile also contains *Cholesterin*, a non-saponifiable crystalline fatty substance, various products of disintegration, as Leucine, Tyrosine, Xanthin, and Hypoxanthine; and also certain colouring matters, Cholepyrrhin, Bilifulvine, and Biliverdine, whose relationship with the colouring matter of the Blood, first suggested by Virchow,[†] has been rendered still more probable by the discovery of Zenker[‡] of crystals of Hæmatoidin in inspissated Bile, by the circumstances that both contain iron, and by the observation of Gübler[§] that Biliphæin and Hæmatin give the same play of colours with $N O_5$, except that the green colour is most persistent in the former and the violet in the latter. It is remarkable that, notwithstanding the comparatively-minute proportion in which these last substances exist in ordinary bile, cholesterin should usually be the principal ingredient of the biliary concretions which are frequently found in the gall-bladder and bile-ducts;

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[*] The soda salts of these acids may be readily obtained by evaporating Ox bile to dryness, treating the residue with alcohol, and adding ether to the alcoholic solution till a dense precipitate is permanently thrown down. After some hours the Glycocholate of soda crystallizes out in silky prisms and bundles, whilst the Taurocholate of soda remains in the form of oily drops. Both are hygrometric and very soluble in water, and the acids can be separated from one another by acetate of lead, which precipitates the Glycocholic but not the Taurocholic. The formula for the Cholic acid is stated to be $C_{48} H_{40} O_{10}$. In Glycocholic acid it is in combination with Glycine, the formula for which is $C_4 H_5 N O_4$, and in Taurocholic acid with Taurine, which is represented by the formula $C_4 H_7 N S_2 O_6$. This separation of Tauro- and Glycocholic acids is, it is to be remembered, purely artificial, and the result of the action of reagents; and though there is a general resemblance in the characters of the Bile in different species of animals, yet there are minor differences which are very distinctive. Thus Dr. Dalton states that he has been unable to obtain any crystals from Human bile corresponding to those of the Glycocholate of soda procured, as above mentioned, from Ox bile. On the other hand, the entire biliary ingredients of human Bile are precipitated by both or either of the salts of lead. See the excellent Section 'On the Liver and its Functions,' in Dr. Dalton's "Human Physiology," 1861.

[†] "Archiv f. Path. Anat." band i., 1848, p. 421.

[‡] "Jahresbericht von der Gesellsch. f. Natur und Heilkunde in Dresden," 1858, p. 53.

[§] "Gaz. Méd. de Paris," 1859, p. 469.

and that the bile-pigment with its calcareous base should also occasionally accumulate, so as to form solid masses which consist of little else. Strecker* has recently found in the bile an energetic base which he has termed Choline ($C_{10} H_{13} NO_2$), and Lecithin, a substance allied to the fats.

375. We have now to inquire into the conditions under which the Secretion of Bile takes place; and one of the most important of these, is the supply of Blood which the Liver receives. How far the blood supplied by the Hepatic Artery is the immediate source of the secretion has not been quite satisfactorily determined. Kottmeier† and Küthe‡ found that no bile was secreted after ligature of this vessel, and they attribute the result to an alteration taking place in the nutrition of the cells destined to form the bile. Schiff, however, was unable to detect any diminution in a large dog upon which he had performed the same operation. It is certain, however, that the Hepatic artery may indirectly furnish the supply of blood necessary for the secretion; for although, if the Vena Portæ be suddenly tied, the flow of bile is immediately stopped, and death ensues in the course of a few hours; yet if the obliteration be slowly effected, either by the gradual tightening of a ligature,§ or, as occasionally happens, from disease, the secretion of bile still continues, though in diminished quantity. In such instances it probably proceeds from the blood of the hepatic artery, the capillaries of which discharge themselves into the lobular plexus of veins, and in cases of malformation have been actually observed to pass into the ramifications of the umbilical vein, forming a plexus in the lobules that exactly resembled the ordinary portal plexus.|| It may also sometimes be due to the presence of the accessory Venæ Portarum, which have been noticed by Sappey.¶ According to Bernard,** the engorgement of the Vena Portæ consequent upon its slow obliteration, is relieved by the presence of small anastomotic branches with the Renal Vein, corresponding to the Venous system of Jacobson, found in the lower Vertebrate classes.††—The fact that the secretion of Bile is normally formed, in great part at least, from *venous* blood, has been commonly connected with the hydrocarbonaceous nature of its chief components, which must exist (it is considered) in larger proportion in such blood than in that of the arteries. But it must be borne in mind, that the urinary excretion, which is undoubtedly formed at the expense of the products of the disintegration of the tissues, is secreted from arterial blood; and since the bile is, as it were, the *complement* of the urine (the ultimate components of the two together making-up the composition of blood),‡‡ there seems no reason why arterial blood should not furnish its

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* P. Schützenberger, "Chimie appliqué à la Physiologie Animale," 1864, p. 170 *et seq.*

† "Zur Kenntniss der Leber," Wurzburg, 1857.

‡ "Studien des Physiolog. Institut. zu Amsterdam," 1861.

§ Oré, "Comptes Rendus," 1856, p. 463.

|| Such, at least, was found to be the case, in the only instance in which the Liver was examined with sufficient care. See Kiernan, loc. cit.

¶ "Gaz. Méd." 1859, p. 489.

** "Leçons sur les Liquides de l'Organisme," 1859, vol. ii. p. 195.

†† For other anastomotic branches, see Schiff in Schweiz. "Zeits. f. Heilkunde," band i., 1862.

‡‡ It has been pointed-out by Prof. Liebig, that if we add to half the formula representing the ultimate composition of *bile*, the formula of *urate of ammonia* (which is the

materials, as abundantly (or nearly so) as venous. The real explanation of the peculiar relation of the Liver to the Venous circulation, is probably to be found in the action of the organ upon the matters newly absorbed into the circulation from the alimentary canal. That this action is not only assimilative, as already shown (CHAP. IV. Sect. 3), but is also to a certain extent depurative, appears from the fact that the liver tends to remove from the blood, and to store-up in its own substance, certain foreign matters of an injurious kind,—such as copper and arsenic,—which have found their way into the tributaries of the portal system. This seems also to be the case with respect to pus, which, when taken-up from ulcers in the intestinal walls, is stopped in the liver, and not unfrequently gives rise to abscesses in its substance.*

376. The chief constituents of the Bile appear to be elaborated in the Liver itself, and not to be preformed in the Blood; since, although the tests for the biliary acids are far more delicate than those employed for the detection of urea, no trace has been discovered of them in the blood of animals whose liver has been extirpated, though it might be expected that if, like the components of the urinary secretion, they pre-exist in the circulating current, and are merely eliminated from it by the action of the liver, they would accumulate in it when that elimination is checked by the removal of the secreting organ.† Biliverdine (Harley) and Cholesterine, however, appear to be always present in the blood, and are therefore probably preformed.—Even though the materials of the biliary secretion, however, should receive their complete and characteristic form in the liver itself, it is not less certain that they are produced at the expense of substances of an excrementitious character, whose retention in the circulating current would be injurious; this being strikingly demonstrated by the disturbance of the functions generally, and especially of those of the Nervous system, which is consequent upon the suspension of the secreting process. When the suppression is complete, the powers of that system are speedily lowered (almost as by a narcotic poison), the patient suddenly becomes jaundiced, and death rapidly supervenes.‡ When the secretion is diminished, but not suspended, the same symptoms present themselves in a less aggravated form. It is probable that much of the disorder in the functions of the brain, which so constantly accom-

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characteristic component of the urine of all animals save Mammalia), the sum gives the proportionals of the ultimate components of dried *blood* or of *flesh*, with the addition of 1 equiv. of oxygen and 1 equiv. of water. For:—

$$\begin{array}{rl}
\tfrac{1}{2}\text{ Equiv. of Biliary matter} = & 38C,\ 33H,\ N,\ 11O \\
\text{1 Equiv. of Urate of Ammonia} = & 10C,\ 7H,\ 5N,\ 6O \\
\hline
\text{The Sum of which} = & 48C,\ 40H,\ 6N,\ 17O
\end{array}$$

And in like manner

$$\begin{array}{rl}
\text{Formula of Blood} = & 48C,\ 39H,\ 6N,\ 15O \\
\text{1 Equiv. of Water} + \text{1 Equiv. of Oxygen} = & H,\ 2O \\
\hline
 & 48C,\ 40H,\ 6N,\ 17O
\end{array}$$

Although these formulæ can by no means be supposed to represent the process which actually takes place, yet the coincidence is so close, as to indicate that the complementary relation spoken-of above has a real existence.

* See Dr. G. Budd's "Treatise on Diseases of the Liver," 2nd edit., chap. ii., sect. 1.

† See Frerichs' "Clin. Treat. on Dis. of the Liver," Syd. Soc. Trans., vol. i., 1860, p. 81 *et seq.*

‡ See Prof. Alison in "Edinb. Med. and Surg. Journ.," vol. xliv.; and Dr. Budd, Op. cit., chap. iii.

panies deranged action of the digestive system, is due to the less severe operation of the same cause; namely, the partial retention within the blood, of certain constituents of the bile, which should have been eliminated from the circulating fluid. Such an abnormal accumulation, which may depend either on a deficiency in the functional activity of the liver, or on an excess of the excrementitious matters brought to it for elimination, is habitual in some persons; and it produces a degree of indisposition to bodily or mental exertion, which it is difficult to counteract. More, probably, is to be gained in such cases by the regulation of the diet, especially the reduction of its hydrocarbonaceous components, and by active exercise (which, by augmenting the respiration, will promote the elimination of any superfluity of this kind through the lungs), than by continually inciting the liver to increased functional activity, by medicines which have a special power of temporarily augmenting its energy.—The excrementitious character of the Biliary secretion is very strikingly indicated by its formation during fœtal life;* which, as it can then have reference neither to the function of Digestion nor to that of Respiration, must be regarded as having for its purpose to free the blood of matter which would be injurious to it. And this matter can hardly arise from any other source than the 'waste' of the tissues (consequent upon the limited duration of their existence), which takes place even when the life of the organism is most purely vegetative.

377. From what components of the Blood the materials of the biliary secretion are immediately derived, is a question that cannot yet be answered with more certainty than the preceding. The close resemblance in composition between the resinous acids of bile and the ordinary fats (especially olein), naturally suggests the idea that they are drawn from the fatty matters of the blood; an opinion which was supported by Lehmann, on the grounds—first, of the diminished proportion of fat contained in the Hepatic, as compared with the Portal Venous blood; secondly, of the increase in the quantity of bile observed after rich fat food; and thirdly, of the emaciation which occurs in animals as a consequence of the formation of a biliary fistula, in spite of abundant supply of albuminous food. It must be acknowledged, however, that there are various objections to this view, both physiological and chemical. Thus it is maintained by Bidder and Schmidt, that the flow of bile is not increased by a predominance of fat in the food, and that animals fed exclusively on fat do not secrete more bile than those entirely deprived of food: whilst it has been found by Nasse, that it is to the presence of a large amount of albuminous compounds in the food that any great augmentation in this secretion is due.† The increase of the secretion after each ordinary ingestion of food (§ 97), and its marked and progressive diminution in animals entirely deprived of aliment (as determined by MM. Bidder and Schmidt), seem to indicate that its materials may be directly derived in part from albuminous materials which do not undergo metamorphosis into tissue; whilst on the other hand, there is every reason to believe, that

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* It has been shown by Simon and Frerichs, that the *meconium* which is contained in the intestinal canal at birth, is chiefly composed of accumulated bile; and F. Hoppe has recently ("Virchow's Archiv," 1863, p. 519) maintained that the bile is not re-absorbed, but undergoes decomposition in its course through the alimentary canal, into butyric, baldrianic, capronic, and caprylic acids.

† See Prof. Lehmann's "Physiologischen Chemie," 2nd edit., band ii. pp. 64-66.

the production of the components of bile is a necessary part of those processes of retrograde metamorphosis, by which the materials of the effete tissues are removed from the system.—In regard to the influence of the Nervous system on the secretion of Bile, it has been observed by Goldschmidt[*] that it is considerably decreased by section of one Vagus, providing the respirations diminish in frequency, but not otherwise; when both Vagi were cut the secretion diminished to one-half, which was probably attributable to the embarrassment of the lungs and heart, consequent upon the operation, producing engorgement of the liver, a condition which, when produced by other causes, is also accompanied by diminution in the secretion of Bile;[†] and this explanation is supported by the fact, that section or irritation of the Vagus below the Diaphragm exerts no influence on the amount of bile secreted. But besides the secretion of Bile, it appears that another purpose is fulfilled by the Liver—the production of an amyloid substance termed Glycogen; and we shall now proceed to consider the chief facts which have been ascertained in reference to this so-called 'Glycogenic function of the Liver.'

378. It had long been well known that Vegetables were capable of producing Starch and Sugar from the inorganic materials of their food, but the presence of the former as a constituent of the animal body, in the test of one of the Tunicata, announced by Dr. Schmidt, and corroborated by the observations of Lowig and Kolliker,[‡] was considered to be only interesting because it destroyed what had till then been looked upon as one of the most important means of distinguishing the tissues of the animal from those of the plant. In 1848, however, Bernard[§] observed, that whilst the Blood of the system generally, and that of the Vena Portæ in particular, in an animal fed exclusively on meat, appeared to be destitute of Sugar, a very notable quantity could be detected in the blood of the Hepatic Vein and right heart—that is to say, in the blood which had passed through the Liver. He immediately inferred that a new function, the formation of Sugar, was to be attributed to the Liver; that the sugar so produced was thrown into the circulation, and then, by undergoing combustion, ministered to the maintenance of animal heat. He was supported in this view by the authority and analyses of Lehmann,[||] who suggested that the Sugar might proceed from the decomposition of albuminous compounds, since there was a smaller quantity of albumen in Hepatic as compared with Portal Venous blood; and there were also good chemical grounds for supposing that albumen might split up into nitrogenous compounds, represented by the conjugated biliary acids (which also contain the sulphur), and into non-nitrogenous compounds represented by Starch, Glycogen, and Sugar. Bernard[¶] himself, however, was disposed to consider that the Bile and Sugar were produced independently of one another; first, because the formation of Sugar was most active at a much earlier period after food than that of Bile; and secondly, because in one of the Mollusca (Limax flava) he found that the liver secreted sugar

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[*] Experiments made in conjunction with Hausmann and Lissa in the "Proceedings of the Breslau Institut," Heidenhain, 1862.

[†] See Körner and Strube's Experiments in the "Proceedings of the Breslau Institut," 1862.

[‡] "Annales des Sciences Naturelles," 1846.

[§] "Archives Gén. de Médecine."

[||] "Comptes Rendus de l'Acad. des Sciences," 1855, p. 587.

[¶] "Leçons," 1854-55, p. 93 *et seq.*

and bile alternately, the former during, the latter after digestion. The observations of Bernard, from their novelty and interest, attracted the attention of many chemists and physiologists, and it was soon shown that sugar, though in comparatively small proportion, was frequently present in the blood of the general circulation, and of the Vena Portæ, as well as in that of the Hepatic vein. Thus Chauveau* found in the arterial blood of a Horse, which had fasted for six days, 0·06 per cent of Sugar, and in the systemic venous blood, 0·05 per cent. Colin also detected traces of Sugar in the Chyle and Lymph. Very careful investigations were made by Dr. Harley, Poisseuille, Lefort,† and others, to determine the proportion of Sugar in the Liver, and in the blood drawn from different parts of fasting animals. In one of the experiments of Poisseuille and Lefort, a dog which had been kept fasting for 60 hours, but had been supplied with a moderate quantity of horseflesh an hour and a half before death, was found to contain—

In 100 parts of the	Parts of Sugar.
Liver	1·487
Thoracic Lymph	0·141
Blood of the Hepatic Vein	0·821
None elsewhere.	

Again, in a horse in full digestion, after a meal of oats, they found—

In 100 parts of the	Parts of Sugar.
Liver	2·292
Blood of Hepatic Vein	1·128
Chyle	0·222
Lymph	0·442
Blood of the Vena Portæ and elsewhere	0·065

Lastly, in examining the Liver of various animals, they obtained from—

100 parts of the Liver of the	Parts of Sugar.
Fish	0·484 to 1·5
Frogs	0·315 ,, 0·632
Birds	2·164 ,, 0·632
Goat	— ,, 1·092
Rabbit	1·000 ,, 1·163
Cat	0·807 ,, 2·305

Bernard also found that the liver of the calf usually contains from 2 to 4 per cent of sugar; of the rabbit, from 2·2 to 2·7; and of the dog, from 1·0 to 1·3 per cent; whilst in his examinations of the liver of the human subject, he found from 1·79 to 2·142 per cent of sugar in criminals, and in the fœtus of six months, 0·77 per cent. Stokvis‡ also obtained 0·54 per cent of sugar from the liver of a fœtus at the 6th or 7th month, but as much as 3·42 per cent from that of a stillborn mature infant. The much larger proportion of sugar obtained from the liver of Herbivorous as compared with Carnivorous animals, especially after a meal containing much amylaceous or saccharine material, naturally led to the supposition that these substances were derived from the aliment, and were merely deposited in the tissue of the liver; and we accordingly find Sanson,§ after a careful résumé of the whole subject, arriving at the conclusion that vegetables alone are capable of producing starch, a part of which, when

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[*] "Gaz. Méd.," 1857, and "L'Union Méd.," 1857.

[†] "Gaz. Méd.," 1858.

[‡] Henle and Meissner, "Bericht," 1857, p. 254.

[§] "Journ. de la Physiol.," 1858, p. 244; 1859, p. 104.

formed, is applied by the plant to the nutrition of its own tissues, whilst another part, stored up in cells, becomes subservient to the nutrition of Herbivorous animals. In these again, a portion of the starch is consumed in the vital processes, whilst another portion is distributed to the tissues, being especially abundant in the liver; and to this source he believed the sugar contained in the blood of Carnivora to be traceable. This view, however, became untenable when it was shown that in animals fed exclusively for months on ordinary butchers' meat, in which no trace of starch or sugar is present, the presence of sugar in the liver could readily be demonstrated. In such cases it was obvious that the sugar could not be derived directly from the aliment, but must have been the result of metamorphoses taking place in the liver itself.

379. In the meanwhile Bernard, pursuing his investigations, was struck with the circumstance, that if the vessels of the Liver were thoroughly cleared of Sugar by the injection of water, a fresh supply of that substance could be obtained, after the lapse of a few hours, upon re-injection; showing not only that the production of sugar must be external to the vessels, and in the very substance of the organ itself, but also that it is capable of taking place quite independently of all vital action. From a consideration of these facts, he was led to inquire whether there might not be some substance formed by and pre-existent in the hepatic tissue, from the metamorphosis of which the sugar proceeded; and he, coincidently with Hensen* and Pavy,† was soon successful in obtaining a peculiar substance possessing properties intermediate between those of starch and dextrine, and capable, under the action of ferments, of being readily converted into sugar, and of ultimately undergoing alcoholic or lactic acid fermentation. This substance was termed Glycogene by Bernard; Hepatine, or Amyloid substance, by Pavy; and Zo-amyline by Rouget. It was obtained by Bernard by immersing the liver of a recently-killed animal in hot water to coagulate the albumen, then bruising it in a mortar, and filtering the liquid through animal charcoal. On the addition of alcohol or of glacial acetic acid, the new substance was precipitated as a white and tasteless amorphous material, soluble in water, but incapable of effecting the reduction of the salts of copper. Iodine coloured it of a reddish violet tint, which disappeared on heating it to 176° F., but reappeared on cooling. According to Pelouze, its chemical formula was $C_{12} H_{12} O_{12}$. In all essential respects, then, Glycogen resembles starch—so closely indeed, that Nageli considered them to be identical; and since the granules of this substance were observed within the hepatic cells under the microscope, by Bernard, Schiff, and others, whilst the quantity of this new material was found to vary with the amount and kind of food, as had formerly been shown to be the case with the sugar, it was very generally supposed that a double origin might be admitted for the amyloid material. On the one hand, it might proceed from the disintegration of the albuminous constituents of the food, as formerly suggested by Lehmann for the sugar; and on the other, it might be due to the accumulation and metamorphosis in the hepatic tissue of the amylaceous and saccharine materials absorbed in digestion. The great influence exercised

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* "Archiv f. Path. Anat.," band xi. p. 395.

† "Guy's Hospital Reports," 1858, p. 291; 1859, p. 204; 1861, p. 197. "Phil. Trans.," 1860.

by the nature of the food on its amount was clearly shown by Dr. Pavy,* who found, on analysing the livers of dogs fed on exclusively animal diet, about 7 per cent of amyloid substance; whilst on those fed on meat and sugar it amounted to 14·5 per cent; and in those fed on vegetable diet alone to 17 per cent. Bernard and Schmidt, however,† found that the quantity of glycogen and sugar obtained from the liver was greatest when the food was highly albuminous, and fell to a minimum when the animal was fed on starch or fat. And the experiments of Stokvis on the effects of oleaginous food are in accordance with these statements.‡

380. The presence of an amyloid material having been thus shown to be constant in the liver, and to precede the formation of sugar, it was supposed that some ferment was requisite by which, either in the hepatic cells themselves, or after the absorption of the starch into the blood, its conversion into sugar could be rapidly effected. Many efforts were made to ascertain the source of this ferment; and the spleen, thymus, thyroid, suprarenal, salivary, and pancreatic glands, were successively extirpated by Schiff,§ without, however, his being able to determine whether any of them were instrumental in its formation. Hensen maintained that the ferment was thrown down with the amyloid substance on the addition of alcohol to the cold aqueous infusion of the liver; that, as Bernard had observed, it was rendered inoperative by boiling; and finally, that it was contained in ordinary arterial blood and in the blood of the vena portæ, the addition of such blood to a solution of glycogen effecting its conversion into sugar. The necessity for the existence of this ferment has been rendered very doubtful by the investigations of Dr. Pavy, which, if they receive confirmation from subsequent observers, establish the following important points:‖—1. That the liver normally and *during life*, whatever may have been the nature of the food, contains little or no sugar, but a

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* "Phil. Trans.," 1860, p. 604. † "Comptes Rendus," 1859, p. 63.

‡ In addition to the two hypotheses above stated as to the origin of Glycogen, a third has recently been put forward by v. Deen ("Donders' Archiv," 1860, iii. p. 49), Poggiale, and others, that it is the result of the metamorphosis of the fatty substances consumed as food or generated in the Liver itself. Küthe and Heynsius ("Studien des Physiolog. Institut zu Amsterdam") especially adopt the latter view, maintaining that the Glycogen proceeds from the decomposition of the conjugated biliary acids re-absorbed in the intestine; for in dogs with biliary fistulæ, Küthe found that the liver contained no Glycogen and a very small proportion (0·2 per cent) of sugar, whether they had or had not been previously fed with meat; whilst if healthy dogs, after many days of fasting, and in which there should normally have been but a small proportion of Glycogen present, were fed with 1 oz. of *Taurine*, and were killed after two or three hours, an abundant supply of Glycogen could be obtained from the liver. And again, theoretically, Urea and Glycogen may very easily be derived from the decomposition of *Glycine*, thus:—

$$\begin{array}{rl} \text{2 Eq. of Urea} \quad 2\,(C_2\,H_4\,N_2\,O_2) = & C_4\,H_8\,N_4\,O_4 \\ \text{1 Eq. of Glycogen}\ (C_{12}\,H_{12}\,O_{12}) = & \underline{C_{12}\,H_{12}\,O_{12}} \\ \text{4 Eq. of Glycine}\ 4\,(C_4\,H_5\,N\,O_4) = & C_{16}\,H_{20}\,N_4\,O_{16} \end{array}$$

And it has already been shown that the quantity of Urea rises in diabetes, whilst the increased size of the liver in this disease is indicative of increased functional activity. This mode of accounting for the origin of the amyloid substance is not, however, a very satisfactory or probable one, either on chemical or on physiological grounds.

§ "Unters. üb. die Zuckerbildung der Leber," Wurzburg, 1859.

‖ See his work on Diabetes, 1862. It is right to add that the correctness of some of his experiments and conclusions has been called in question by Dr. Harley, operating in conjunction with Dr. Sharpey: see "Med. Times and Gaz.," 1860, vol. i. p. 158.

considerable proportion of amyloid substance; since if it be removed from the body instantly after death, and subjected to the action of caustic potash, or of extreme cold, no saccharine reaction can be obtained, though the presence of the amyloid substance can easily be shown. 2. That, *during life*, there is under ordinary circumstances very little difference in the amount of sugar contained in different specimens of blood, whether withdrawn from the systemic arteries or veins, the portal vein, or (by means of a catheter introduced through the jugular vein)* from the right auricle; the latter, of course, containing a large proportion of hepatic venous blood: the quantity of sugar present in all instances being extremely small, and varying from 47 to 73-1000ths of a grain per cent. 3. That *during life*, therefore, very little amyloid substance is taken up by the blood in its passage through the liver, as indeed might be anticipated from its low power of dialysing through animal membranes. On the contrary, after death, and frequently from various disturbing causes during life, a conversion of the amyloid substance into sugar takes place in the substance of the liver itself, and the sugar so formed then quickly appears in the blood, often to so great an extent as to occasion diabetes.

381. At an early period of the history of the glycogenic function of the Liver, it was found that the formation of glycogen could be influenced through the nervous system. Bernard, for instance, observed that when the floor of the fourth ventricle was pricked with a needle, so great an increase was effected in the quantity of sugar generated, that that substance was discharged by the urine, a temporary condition of diabetes being established; whilst on the contrary, section of the spinal cord just below the origin of the phrenic nerves, and section of the vagi in the neck, appeared to check its production. These singular facts have received some elucidation from the experiments of Schiff,† who has shown that the vaso-motor nerves of the abdominal organs arise from the Thalami optici and in the cerebral peduncles, from whence they descend, lying side by side in the Medulla oblongata, and subsequently pass down the anterior columns of the cord, emerging at the roots of the Sympathetic, to supply the vessels. When the floor of the fourth ventricle is pricked, these nerves are irritated, which causes enlargement of the vessels of the liver and hypersecretion of glycogen; whilst on the other hand, if the anterior columns of the cord be cut, the irritation produced by the puncture is not conveyed downwards, and no diabetes results. Hensen and Grafe have also noticed that section of the splanchnic nerves, or irritation applied to the cut surface of the central extremity of a pneumogastric nerve, occasions an increased production of sugar, in both cases probably as a consequence of the dilatation of the abdominal blood-vessels. Similar results have been obtained by Pavy after division of the sympathetic cord in the neck, and after division of the sympathetic plexus accompanying the vertebral arteries.‡

382. The influence of medicinal agents upon the glycogenic function of the Liver has received but little attention, though various substances are known to be capable of inducing diabetes. Cozé§ found the proportion of sugar nearly doubled both in the liver and in arterial blood

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* See on this point also MacDonnell, "Proceedings of the Royal Irish Society," 1860.

† "Archives Gén. de Médecine," 1861, vol. i. p. 113

‡ See "Guy's Hosp. Rep.," 1859, p. 204.

§ "Comptes Rendus,"

after the administration of morphia. Pavy* observed well-marked diabetes in animals after the administration of 1 to 2 oz. of phosphoric acid, and also after poisonous doses of strychnia, when the circulation was maintained by artificial respiration. Harley obtained the same result in himself after eating freely of asparagus. He noticed it also in animals after the injection of ether, chloroform, liquor ammoniæ, and methylated spirit, into the portal vein.† Reynoso‡ induced diabetes by causing animals to respire the vapour of benzine and acetone, and found that it followed asphyxia, slowly produced by the inhalation of carbonic, hydrosulphuric, and hydrocyanic acid gases. Whilst it is generally admitted that the phenomena of diabetes in most of these cases are due to disturbance of the glycogenic function of the liver, the appearance of the sugar has been attributed by some to paralysis of the Sympathetic, occasioning a freer circulation through the liver, which is again accompanied by an augmented production and absorption of the amyloid substance, and a consequent increase in the proportion of sugar in the blood, so that at length it appears in the urine; whilst others, as Reynoso, maintain the saccharine impregnation of the urine to be referrible to the grave disturbance of the respiratory function constantly present, which, by diminishing the proportion of oxygen absorbed, checks the combustive operation by which the sugar derived from the amyloid substance is eliminated from the system. The administration of large doses of caustic potash, or of carbonate of soda, is stated by Dr. Pavy to prevent the occurrence of diabetes under circumstances in which it would otherwise have been induced.

383. Taking all these considerations into account, we seem entitled to conclude, that besides its operation as an Assimilating organ, whereby it helps to prepare histogenetic materials for conversion into blood and solid tissue, the Liver is capable both of *producing* and of *storing-up* amylaceous material in its cells, exerting its Secretive action in the former case in separating the hydrocarbonaceous portion of the protein-compounds which are destined to undergo retrograde metamorphosis, as being either *superfluous* or *effete;* and this under the three forms of Amyloid substance, Fat, and Bile. The two former, if not at once removed by the blood-current, remain stored-up in the liver itself, as a pabulum for respiration; the latter, being of use in the digestive operation, is first poured into the alimentary canal, from which, however, the greater part is subsequently reabsorbed, its components being oxidated and then eliminated through other channels, the Hydrocarbon as water and carbonic acid through the Lungs, the Sulphur as sulphuric acid through the Kidneys. As an appendix to the history of Glycogeny, it may here be remarked that in 1859 Bernard§ detected the presence of Amyloid substance in the Placenta and in various embryonic cellular tissues; and endeavoured to show that these performed the functions of the liver vicariously during the earlier months of fœtal life. Virchow also, in a course of pathological investigation spread over many years, has shown that the production of starch in the animal economy is not limited to the

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* "Proceedings of the Royal Society," No. 35.

† See "Med.-Chir. Review," 1857, Oct. 1862, and "Proceedings of Royal Society," 1860.

‡ "Annal. des Sci. Nat." 1855, p. 131.

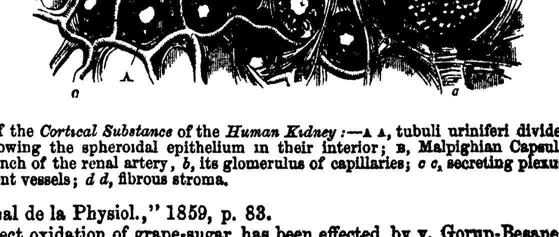
§ Brown-Séquard, "Journal de la Physiol.," 1859, p. 30.

liver, but may frequently be observed in the nervous system and spleen as the result of disease; whilst Meckel discovered similar degenerations in the kidneys, muscles, cartilages, and other organs of the body, the amyloid substance making its appearance partly between the elements of the tissues and partly within them. Upon these grounds a wide and comprehensive generalization has been made by Rouget,* to the effect that, seeing under what various forms the amyloid substances present themselves in the living body,—as the true starch of Carter, the corpora amylacea of Virchow, and the glycogen of the liver and embryonic membranes,—and how widely they are distributed through the intimate structure of different tissues, it is impossible to regard their development as a function peculiar to, or localized in the liver, or any special organ; nor can it even be admitted to be performed exclusively by any system of tissues, as the Epithelial. On the contrary, it is to be considered as a phase of life—a property belonging to cells and the elements of tissues generally, establishing a perfect conformity in the tissues of all animals, and representing an incipient stage of disintegration and decay of cell-structure, a downward tendency, which is immediately carried further by its direct† or indirect oxidation and elimination from the body in the form of carbonic acid and water.

3. *The Kidneys.—Secretion of Urine.*

384. The *Kidneys* cannot be regarded as inferior in importance to the Liver, when considered merely as Excreting organs; but their function only consists in separating from the blood certain effete substances which are to be thrown-off from it, and has no direct connection with any of the nutritive operations concerned in the introduction of aliment into the system. The following are the points in the minute structure of these

Fig. 81.



Section of the *Cortical Substance* of the *Human Kidney*:—A A, tubuli uriniferi divided transversely, showing the spheroidal epithelium in their interior; B, Malpighian Capsule; *a*, its afferent branch of the renal artery, *b*, its glomerulus of capillaries; *c* c_1 secreting plexus formed by its efferent vessels; *d d*, fibrous stroma.

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* "Journal de la Physiol.," 1859, p. 83.

† The direct oxidation of grape-sugar has been effected by v. Gorup-Besanez, by dissolving it in a weak alkaline solution and passing ozone through the liquid, when carbonic and formic acids are gradually formed without the appearance of any intermediate compounds.

organs, which are of most importance in their Physiological relations.* Their glandular and vascular elements are imbedded in a stroma composed of interlacing fibres (Fig. 81, *d d*); this is more abundant in the medullary, than in the cortical substance; but at the surface of the gland it is condensed into a continuous membrane, which is loosely connected with the proper capsule. The distinction between the *cortical* and the *medullary* part of the Kidney essentially consists in this,—that the former is by far the most vascular, and the plexus formed by the tubuli uriniferi seems to come into the closest relation with that of the sanguiferous capillaries, so that it is probably the seat of the greater part of the process of secretion; whilst the latter is principally composed of tubes, passing in a straight line from the former towards their point of entrance into the ureter. The tubuli uriniferi, in passing outwards from the Calices, divide and subdivide in a dichotomous manner, at least ten or twelve times, their number becoming thus greatly increased, whilst their diameter diminishes from about 1-300th to about 1-600th of an inch. Each tube on arriving at the cortical portion becomes much convoluted, and terminates in a dilatation which has received the name of the Malpighian Corpuscle. The total number of the tubes is estimated by Huschke at about two millions (Fig. 84). They are lined with polygonal epithelium (Figs. 83, 85), the cells of which contain round nuclei and a finely-granular albuminous fluid,

FIG. 82*.

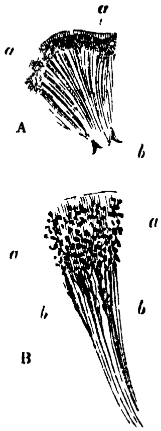
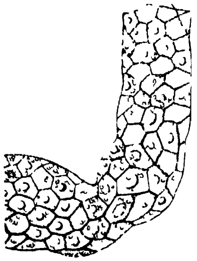


FIG. 83.†



* Portion of the *Kidney* of a new-born infant:—A, natural size; *a*, *a*, Corpora Malpighiana, as dispersed points in the cortical substance; *b*, papilla.—B, a smaller part magnified; *a*, *a*, Corpora Malpighiana; *b*, tubuli uriniferi.

† Portion of one of the *tubuli uriniferi*, from the Medullary substance of the kidney of an adult; showing its tesselated epithelium.

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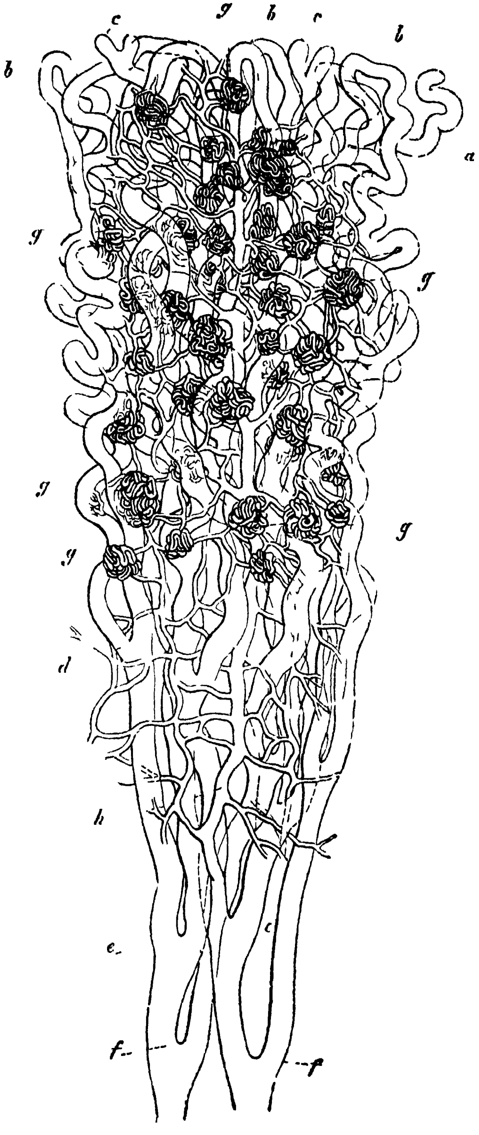
* See especially Mr. Bowman's Memoir in the "Philosophical Transactions," 1842; also Goodsir in "Edinb. Monthly Journal," 1842; Gerlach, Bidder, and Kölliker, in "Müller's Archiv," 1845; Toynbee in "Med.-Chir. Trans.," 1846; Johnson in "Cyclop. of Anat. and Phys.," art. 'Ren.'; Gairdner in "Edinb. Monthly Journal," 1848; Frerichs, "Die Bright'sche Nierenkrankheit und deren Behandlung," 1851; and Kölliker, "Mikroskopische Anatomie," and "Man. of Hum. Histol." (Sydenham Soc.); "Micros. Anat.," 1860; Isaacs, "Trans. N. Y. Acad. of Med.," vol. i. 1857; Henle, "Göttingen Abhandlungen," 1862.

with, in many instances, small dark fat-drops and a little pigment. They are very prone to alteration, and when immersed in water rapidly become

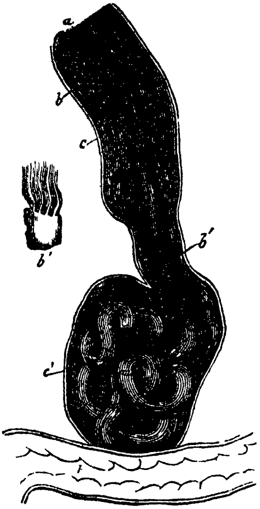
FIG. 84.



A small portion of the *Kidney*, magnified about 60 times:—*a*, supposed cæcal extremity of a tubulus uriniferus; *b*, *b*, recurrent loops of tubuli, *c*, *c*, bifurcations of tubuli; *d*, *e*, *f*, tubuli converging towards the papilla; *g*, *g*, *g*, Corpora Malpighiana, seen to consist of convoluted knots of blood-vessels, connected with a capillary network; *h*, arterial trunk.

distended and pale. The cell-wall is remarkable for its delicacy; and after its destruction free nuclei, interspersed among amorphous granules, alone remain in the interior of the tubules. The cells lining the tortuous portion of the tubules are somewhat larger than those in the interior of the straight. On examining one of the Corpora Malpighiana with a high magnifying power, it is found to consist of a convoluted mass of minute blood-vessels (Fig. 84, *g*); and this is included in a flask-like dilatation of one of the tubuli uriniferi (Figs. 81, B, 85, *c*, *c′*). According to Mr. Bowman, this dilatation proceeds only from the termination of the tubulus; and this seems to be usually the case, although it appears not improbable that it may sometimes be a lateral diverticulum, as described by Gerlach (loc. cit.). The epithelium, which elsewhere lines the tube, is altered in appearance where the tube is continuous with this capsular dilatation (Fig. 85, *b′*); being there more transparent, and furnished with cilia (as shown at *b″*), which, in the Frog and other Reptiles, may be seen for many hours after death, in very active motion, directing a current down the tube. Further within the capsule, this epithelium becomes excessively delicate, and sometimes disappears altogether.*

Fig. 85.



Uriniferous Tube, Malpighian Tuft, and Capsule, from *Kidney of Frog*:—*a*, cavity of the tube; *b*, epithelium of the tube; *b′*, ciliated epithelium of the neck of the capsule; *b″*, detached epithelium-scale; *c*, basement-membrane of tube; *c′*, basement-membrane of capsule; *m*, convoluted capillaries of the Malpighian tuft.

385. The absolute quantity of blood traversing the kidneys is wonderfully great, amounting, according to the calculations of M. Brown-Séquard,† to nearly 2000 lbs. per diem. The Circulation of Blood through the

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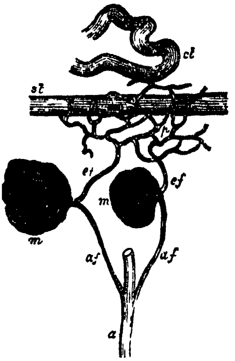
* Another and a very different account of the structure of the Kidney has recently been given by Henle ("Göttingen Abhandlungen," 1862, p. 247). He describes two systems of tubes; one commencing by a network in the cortical substance, which is best marked near the free surface, the tubes of which, collecting into bundles, run towards the pyramids, and uniting two and two, ultimately open on the apex of the papillæ. The tubes of the second system also commence in the cortex of the kidney, where they form blind terminal dilatations enclosing the glomeruli. They intertwine with the plexus formed by the first set, then run parallel with the bundles of the latter until they reach the medullary portion, in which they unite two by two into loops. This set has no openings on the pyramids or elsewhere; it constitutes, therefore, a closed system of tubes. The epithelium of the first set is always clear and distinct, of the columnar variety, increasing in size towards their free or papillary termination, the epithelium of the second set is much less distinct, and consists of somewhat flattened cells, which often resemble nuclei. The diameter of the first set with open mouths, which Henle believes to be destined for the separation of the urinary salts, &c., is two or three times greater than that of the second or closed variety, whose function is the elimination of the water, though it is difficult to understand how it escapes.

† "Journ. de la Physiol.," 1858, t. i. p. 305.

Kidney presents a very remarkable peculiarity. The supply is derived in Man (as in other Mammalia) direct from the *arterial* system; though in Fishes and Reptiles the urinary apparatus is connected, as well as the biliary, with the *portal venous* system, and even in Birds a portion of its blood is derived from the latter. But although this organ is supplied from the Renal Artery, yet it is not to its proper secretory apparatus that the blood of the artery is distributed in the first instance; for, on entering the kidney, this vessel speedily and entirely divides itself into minute twigs, which are the *afferent* vessels of the Malpighian tufts (Figs. 81, *a*, 86, *af*). After it has pierced the capsule, each twig dilates; and suddenly divides and subdivides into several minute branches, terminating in convoluted capillaries, which are collected in the form of a ball (Figs. 81, *b*, 86, *m m*); from the interior of the ball, the solitary *efferent* vessel, *ef*, arises, which passes out of the capsule by the side of the single afferent vessel. This ball was supposed by Bowman to be loose and bare in the capsule, being attached to it only by its afferent and efferent vessels; but the more recent examinations of Kolliker,* and of Dr. Isaacs,† appear to prove that it is covered with oval nucleated cells. The *efferent* vessels, on leaving the Malpighian bodies, separately enter the plexus of capillaries (Figs. 81, *c*, 86, *p*) surrounding the tubuli uriniferi (*st*), and supply that plexus with blood; from this plexus the renal vein arises.—Thus there is a striking analogy between the mode in which the tubuli uriniferi are supplied with blood, for the purpose of elaborating their secretion, and the plan on which the hepatic circulation is carried-on. For as the secretion of the Liver is formed from blood conveyed to it by one large vessel, the portal vein, which has collected it from the venous capillaries of the chylopoietic viscera, and which subdivides again to distribute it through the liver, so the secretion of the Kidney is elaborated from blood which has already passed through one set of capillary vessels, those of the Malpighian tufts; this blood is collected and conveyed to the proper *secreting* surface, however, not by one large trunk (which would have been a very inconvenient arrangement), but by a multitude of small ones, the *efferent* vessels of the Malpighian bodies, which may be regarded as collectively representing the portal vein, since they convey the blood from the systemic to the secreting capillaries. Hence the Kidney may be said to have a *portal* system within itself.—This ingenious view of Mr. Bowman finds support from the fact, that in Reptiles the *efferent* vessels of the Malpighian bodies (which receive their blood, as elsewhere, from the renal artery) unite with the renal branches of the Vena Portæ, to form the secreting plexus around the tubuli uriniferi. Here, therefore, the blood of the secreting plexus has a double source, the vessels which

FIG. 86.



Distribution of the Renal vessels, from *Kidney of Horse*:—*a*, branch of Renal artery; *af*, afferent vessel, *m*, *m*, Malpighian tufts; *ef*, *ef*, efferent vessels; *p*, vascular plexus surrounding the tubes, *st*, straight tube; *ct*, convoluted tube.

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* "Man. Mic. Anat.," 1860, p. 408.

† "Trans. of N. Y. Acad. Med.," vol. i. 1857.

supply it receiving their blood in part from the capillaries of the organ itself, and in part from those of viscera external to it; just as, in the Liver, the secreting plexus is supplied in part by the nutritive capillaries of the organ itself, which receive their blood from the hepatic artery, and in part by the blood conveyed from the chylopoietic viscera through the vena portæ.

386. These admirable researches of Mr. Bowman on the structure of the Malpighian bodies, and on the vascular apparatus of the Kidney, have thrown great light upon the mode in which the Urinary secretion is elaborated. One of the most remarkable circumstances attending this excretion, in the Mammalia particularly, is the large but variable quantity of *water*, which is thus eliminated,—the amount of which bears no constant proportion to that of the solid matter dissolved in it. The quantity of water which is passed-off by the Kidneys depends in part upon that exhaled by the Skin, being greatest when this is least, and *vice versâ:* but the quantity of solid matter to be conveyed-away in the secretion has little to do with this, being dependent upon the amount of *waste* in the system, and upon the quantity of surplus azotized aliment which has to be discharged through this channel.—The Kidney contains two very distinct provisions for these purposes. The *cells* lining the tubuli uriniferi are probably here, as elsewhere, the instruments by which the *solid* matter of the secretion is eliminated; whilst it can scarcely be doubted, that the chief office of the Corpora Malpighiana is to allow the transudation of the superfluous fluid through the thin-walled capillaries of which they are composed. "It would indeed," Mr. Bowman remarks,* "be difficult to conceive a disposition of parts more calculated to favour the escape of water from the blood, than that of the Malpighian body. A large artery breaks-up in a very direct manner into a number of minute branches; each of which suddenly opens into an assemblage of vessels of far greater aggregate capacity than itself, and from which there is but one narrow exit. Hence must arise a very abrupt retardation in the velocity of the current of blood." The vessels in which this delay occurs, lie in a capsule, from which there is but one outlet, the orifice of the tube. "This orifice is encircled by cilia, in active motion, directing a current towards the tube. These exquisite organs must not only serve to carry forward the fluid which is already in the cell, and in which the vascular tuft is bathed; but must tend to remove pressure from the free surface of the vessels, and so to encourage the escape of their more fluid contents."—Here we see the essential difference which exists between the *vital* agency concerned in the true Secreting process, and the *physical* power which occasions fluid exhalation or transudation. This difference is precisely the same as that which exists between the *vital* act of selective absorption, and the *physical* operation of endosmose or imbibition. By Imbibition and Transudation, certain fluids may pass through organic membranes, in the dead as well as in the living body; and this passage depends merely upon the physical condition of the part, in regard to the amount and the nature of the fluid it contains, and the permeability of its tissues. If the views of Kölliker and Isaacs are correct, however, the Glomerulus itself possesses, in the cells which cover it, a glandular structure, and is therefore

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* Loc. cit., p. 75.

adapted for the separation not only of water, but also of the proximate constituents of the urine; in corroboration of which, it may be stated that large numbers of the Malpighian tufts are distributed through the kidneys of both Birds and Reptiles, though it is well known that these animals secrete semi-solid urine; whilst in the examination of the kidneys of those who have used strong diuretics, the tufts have been found much congested, and the vessels in some instances even burst; lastly, in cases of jaundice, the capsule of the Malpighian tuft has been found stained with yellow bile-pigment—all circumstances tending to show that they discharge a secretory function.* The transudation of the watery portion of the blood is much increased by any impediment to its flow through the vessels, and also by any causes that produce a diminished resistance in their walls.

387. The Kidney is liable to undergo alterations of its normal structure, from a perversion of its ordinary formative processes, which are of a nature very analogous to those occurring in the Liver, though with differences arising out of the specialities of its conformation. Several different kinds, as well as degrees, of such alteration, have been described (as it now appears) under the general term 'Bright's disease,' which has been applied almost indiscriminately to almost every kind of chronic disease of the structure of the Kidney, whether produced by congestion, inflammation, or fatty degeneration, that is attended with the presence of albumen in the urine. It must not be supposed, however, that any of these lesions are invariably coincident with the presence of Albumen in the Urine: for it has been fully proved, on the one hand, that albumen may present itself in this excretion, without any alteration in the structure of the kidney; whilst it has also been shown, that various forms of Bright's disease may exist, even in an advanced stage, without any albumen being detectible in the urine.† These variations may probably be attributed to two classes of conditions; viz., the state of the albumen in the blood itself, and the state of the capillary circulation in the kidney. We have seen that the weak form of albumen which is first taken-up by absorption from the alimentary canal, is distinguished by its proneness to transudation (§ 112); whilst, on the other hand, the strong albumen of the egg, if injected into the systemic blood-current, or even if introduced in large quantities into the stomach,‡ finds its way out again by the urine, as a foreign substance (§ 92); an assimilating action being required, in the case of each, to give it the normal characters of blood-albumen. It is probably, in part at least, to the want of such perfect assimilation of the newly-absorbed albumen, that we are to attribute the increase of albumen in the urine passed soon after meals, by patients suffering under Bright's disease; something, however, may be due to the simple augmentation of the bulk of the blood, and especially of its solids. But, again, any cause which produces congestion of the vessels of the kidney,

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* See Isaacs, Op. cit.

† See Dr. Begbie in the "Brit. and For. Med.-Chir. Rev.," vol. xii. p. 46.

‡ See Hammond ("Experimental Researches," Philad. 1857, p. 31), who found on restricting himself to a purely albuminous diet, that his urine first contained a great excess of urea, and on the 8th day albumen made its appearance. Bernard also observed its presence in his urine after eating six eggs fasting ("Leçons," 1859, vol. ii. p. 138).

favours the passage of the normal albumen of the blood into the urine;* and thus we see how albuminous urine may be produced by the repulsion of blood from the cutaneous surface to the kidney, or by the determining influence of cantharides or other irritant diuretics, or by any obstruction to the return of blood from the capillary plexus by the renal veins.†

388. The nature and purposes of the Urinary secretion, and the alterations which it is liable to undergo in various conditions of the system, are much better understood than are those of the Bile: this is owing, in great part, to the two circumstances, that it may be readily collected in a state of purity, and that its ingredients are of such a nature as to be easily and definitely separated from each other by simple chemical means. There can be no doubt that the chief purpose of this excretion, is to remove from the system the effete *azotized* matters, which the blood takes-up in the course of its circulation, or which may have been produced by changes occurring in itself. This is evident from the large proportion of Nitrogen in the solid matter dissolved in the urine; and from the crystalline form presented by much of this solid matter when separated,—a form which indicates that its state of combination is such, as to prevent it from conducing to the nutrition of the system. The injurious effects of the retention of the components of the Urinary secretion in the Blood, are fully demonstrated by the results of its cessation; whether this be made to take place experimentally (as by tying the renal artery), or be the consequence of a disordered condition of the kidney. The symptoms of *Uræmia* (as this condition has been appropriately termed) are altogether such as indicate the action of a specific poison upon the Nervous system; affecting either the Brain or the Spinal Cord separately, or both together. In the first form, a state of stupor comes on rather suddenly, out of which the patient is with difficulty aroused; and this gradually deepens into complete coma, with fixed pupils and stertorous breathing, just as in ordinary kinds of narcotic poisoning. In the second form, convulsions of an epileptic character, frequently affecting the whole muscular system, suddenly occur; but there is no loss of consciousness. In the third form, coma and convulsions are combined.—It has been generally supposed that these results are attributable to the accumulation of *urea* in the blood; but clinical observation affords sufficient evidence, that there is no constant relation between the severity of these symptoms and the amount of urea in the circulating system;‡ and experiment has determined that the

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* See Robinson in "Med.-Chir. Transact.," vol. xxvi. p. 51.

† Magendie, indeed, found that the mere injection of about a pint of water into the veins of a large dog was sufficient to cause the urine quickly to become albuminous, the effect remaining for 10 or 12 hours (Bernard, "Leçons," 1859, vol. ii. p. 139). Overbeck ("Sitzungsbericht d. k. Akad. d. Wiss. zu Wien," 1863, p. 189) has also made the curious observation, that *compression* of the renal arteries, whilst it rapidly diminishes the quantity of urine and of urea secreted, also occasions the discharge of albumen in the urine; though if at the same time a ligature be applied to the ureters, the appearance of albumen is completely prevented. Albuminous urine has been observed in certain forms of heart-disease (Rayer), and after certain lesions of the nervous system, as intra-cranial section of the fifth pair of nerves (Longet, "Physiologie," p. 952), and after section of the cerebral peduncles (Schiff).

‡ It has been remarked by Bright, Christison, G. O. Rees, and Frerichs, that urea may often be obtained in considerable quantity from the blood of patients suffering under 'Bright's disease,' who were at the same time free from all nervous symptoms.

other constituents of the urine do not exert any more potent influence.[*] It seems probable, then, that some substance formed at the expense of the normal constituents of urine, rather than either of these substances themselves, is the real poisonous agent in cases of Uræmia; and very cogent evidence has been adduced by Prof. Frerichs, in proof of his idea that the symptoms of this disorder arise from the conversion of the Urea in the circulating current into Carbonate of Ammonia, by the agency of a suitable ferment; so that, however great may be the accumulation, it does not give rise to any serious consequences unless this ferment be also present. Two series of experiments are described by him as supporting this doctrine; the first showing that in cases of uræmic intoxication, a resolution of urea into carbonate of ammonia is actually taking place, ammonia being found in the expired air when the first symptoms make their appearance, and in the blood and in the contents of the stomach after death;[†] and the second proving that the injection of carbonate of ammonia into the circulating current induces a train of symptoms essentially corresponding with those of uræmia, stupor and convulsions occurring either separately or conjointly.[‡]—It seems not improbable that, as in the case of the retention of Bile in the Blood (§ 376), many of the minor as well as of the severer forms of sympathetic disturbance, connected with disordered secretion from the kidney, are due to this directly-poisonous operation of the decomposing constituents of the urine upon the several organs whose function is disturbed; and that many complaints in which no such agency has been until recently suspected,—especially Convulsive affections, arising from a disordered action of the nervous centres,—are thus due to the insufficient elimination of Urea from the Blood.

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[*] Thus Frerichs (as Bichat, Courten, and Gaspard had before done) repeatedly injected from 20 to 40 grammes of filtered human urine, sometimes even with the addition of urea, into the veins of animals, without any ill effects resulting.

[†] It is the conclusion of MM. Bernard and Barreswil,—from the experiments which they have performed to determine, why, after the extirpation of the kidneys, a period of from twenty-four to forty-eight hours always elapses, before the blood shows any decided increase in the quantity of Urea,—that, under such circumstances, the urea is eliminated by the secretions of the intestinal tube, and chiefly by the gastric juice, in the form of an ammoniacal salt; and that no urea can be detected in the blood, until, by a progressive diminution of the vital powers, the intestinal fluids become more and more diminished in quantity, and the metastatic channels for the elimination of urea are closed. Retention of urea in the blood, as they argue, is thus a result, not directly of the suppression of urine, but rather of the loss of vigour which follows it. ("Archiv. Génér. de Médecine," 4me Sér., tom. xiii. p. 449). See also Bernard, "Leçons," 1859, vol. ii. chap. ii.

[‡] On this subject, see the Chapter on 'Uræmia' in the Treatise of Frerichs just cited. His conclusions, however, though quite in harmony with the observations of Lehmann, have been disputed by other pathologists. Thus it has been affirmed ("Brit. and For. Med.-Chir. Rev.," vol. xii. p. 268) that the cause of the symptoms of uræmic poisoning, in cases of advanced 'Bright's disease,' "must be looked-for in an impediment of the metamorphosis of the tissues, in a destruction of the process of endosmose and exosmose between blood and tissues, and perhaps in a generally diminished oxidation-power in the blood;" which is certainly in accordance with the fact now generally admitted, that whilst there is usually a great diminution in the elimination of urea, there is also a deficient formation of it within the system. Thus the analyses of Rosenstein give a mean amount of only 112 grains of urea excreted in 24 hours in this disease, and the uric acid appears to undergo an equal, if not a greater, diminution (see Parkes "On the Urine," p. 385, 1860).—It is difficult, however, to believe that the narcotic symptoms following upon sudden and complete suppression of the urinary excretion, with accumulation of urea in the blood (as shown by analysis), and abating with the elimination of the urea by the re-establishment of the secretion (as happened in the interesting case recorded by Dr. Shearman in the "Edinb. Monthly Journal," March, 1848), can be due to anything else than the direct toxic influence of the urea, or of some product of its metamorphosis.

389. In order to form a correct opinion of the state of the Urinary secretion in morbid conditions of the system, it is desirable to be acquainted with every leading particular regarding its normal character.—Fresh healthy Urine is a perfectly-transparent, amber-yellow-coloured liquid, exhaling a peculiar but not disagreeable odour, and having a bitterish saline taste. The only morphological elements which it normally contains, are pavement epithelium-cells and mucus-corpuscles from the lining of the urinary passages; which, however, are present in healthy urine to only a very small amount. But in certain morbid states of the urine, minute cylindrical bodies are seen, in greater or less abundance, which are obviously derived from the tubuli uriniferi; these are sometimes composed almost exclusively of the epithelial lining of the tubes, of which the cells remain adherent to each other, notwithstanding their detachment from the basement-membrane beneath; whilst sometimes they are fibrinous moulds of the interior of the tubes, formed by exudation of plastic material, and containing blood- or pus-corpuscles; and in other instances, again, they seem to consist of nothing else than the basement-membrane of the tubes themselves. The first of these forms occurs chiefly in desquamative irritation of the kidneys; the second as a consequence of acute inflammation, and the last in the advanced stages of 'Bright's disease.'—In all natural conditions of the Human system (even when a vegetable diet is used), the urine possesses a well-marked acid reaction. When it is left to itself for some time, slight nebulæ, consisting of mucus, are formed in it; and these gradually descend to the bottom. Soon afterwards an unpleasant odour is developed; instead of an acid, an alkaline reaction is presented, in consequence of the decomposition of the urea into carbonate of ammonia; and a precipitation of earthy phosphates then takes place. A turbidity may be produced, however, by the precipitation of urates of soda and ammonia, on the simple cooling of the urine, without any such departure from its normal composition as would properly constitute disease, but under some of the conditions hereafter to be specified (§ 392). But if the urine be turbid when it has first passed from the body, and has a temperature of 98° or 100°, it must be considered as abnormal.

390. *Quantity.*—Dr. Parkes,* who has collected the averages of many different observers, states that 52½ fluid ounces may be considered to represent the mean quantity of urine discharged in 24 hours by healthy male adults between 20 and 40 years of age.† The extremes given by different experimenters are, 35 ounces (Prout), and 81 ounces (Bocker). Almost every intervening number between these two remarkably-different quantities has been stated by one observer or another to be the usual average. Great differences therefore exist, even in healthy adults; and the amount will vary with the quantity of fluid ingested, the external temperature and consequent activity of the cutaneous transpiration, the nature and quality of the food, the tempera-

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* "On the Urine," p. 5.

† This number agrees very exactly with the careful experiments of Dr. Ed. Smith and Kaupp, "Archiv f. Phys. Heilk.," band xiv.

ment of the body, and perhaps even with national peculiarities. Dr. Ed. Smith, from daily experiments made throughout the year, has shown that during a cold summer (half-year from May to October) the average quantity was somewhat more, whilst during a hot summer it was somewhat less, than during the winter six months. With alcohol given to prisoners, there was an average decrease of 20 ounces per day for three days, the quantity of water drank being unchanged. With a day of rest the quantity was less than on days of labour, and there was more on treadwheel days, notwithstanding that the quantity of water drank was the same, and there was more perspiration with the hard labour. It has been clearly shown by Bernard,[*] Ludwig and Goll,[†] that the rapidity with which the secretion of urine takes place, is to a very important extent dependent upon the pressure of the blood in the vascular system. In one of the experiments recorded by M. Goll, the urine being discharged by the ureters at the rate of 30 or 40 grains per minute, the animal was bled, when the flow immediately diminished to 12 grains per minute; but upon transfusing into its veins some blood taken from another animal, it rapidly rose to 188 grains per minute. In like manner, an increased flow of urine occurs when the pressure of the blood is either increased generally, as during digestion (Bernard), or locally in the renal capillaries, as by ligature of the renal veins, or of some of the larger systemic arteries, as the crural and axillary, or by division of the pneumogastric nerves, or after certain lesions of the fourth ventricle; whilst a diminution is observed after the pressure has been diminished by bleeding, or by irritation of the pneumogastrics, which depresses the action of the heart, or by compression of the renal arteries. It is on this principle that the effect of cold in increasing the flow of urine can to some extent be explained; for by contracting the cutaneous capillaries of the body generally, the pressure in the renal vessels must obviously be increased. Women secrete somewhat more urine than men,[‡] and children nearly twice as much in proportion to the weight of the body. Some time, however, usually elapses after birth before the kidneys begin to discharge their function with activity; the urine, up to the third day, being usually scanty, albuminous, destitute of urea, and containing but a small proportion of solid ingredients. When a great excess of fluid has been ingested within a short space of time, it is rapidly discharged by the kidneys, nearly all having escaped at the expiration of 2½ hours after the last portions have been taken.[§]—That the secretion of urine is influenced to an important degree *by the nervous system*, is sufficiently indicated by numerous physiological as well as pathological considerations. The exact origin and nature of that influence is still, however, a subject of controversy. Amongst mental emotions, fear is the one which most powerfully stimulates the kidneys to act, and the effect is equally observable in animals and in man. It may act like cold, by producing congestion of the abdominal viscera generally, since diarrhœa is also frequently induced. The large flow of urine in hysteria, as the attack is passing-off, is well known; and occasionally this occurs also as a critical discharge in some febrile affections. Krimer[‖] was the first who made any direct experiments upon the nerves supplying the kidney: he observed that upon section of the renal nerves, albumen made its appearance in the urine with the colouring matter of the blood, whilst the proper constituents diminished in quantity.* Removal of the cerebrum, cerebellum, or spinal cord, produces but slight change in the quality of the urine. The most interesting observations, however, that have yet been made upon this subject are those of Bernard, who has shown that if a particular point of the fourth ventricle be injured by the introduction of a fine needle, sugar makes its appearance in the urine; and that if this spot be not exactly struck, there is still a considerable increase in the quantity of the urine. It is a matter of common observation that injuries of the spinal cord are followed by changes in the constitution of the urine, which becomes ammoniacal and precipitates phosphates; but it appears to be doubtful whether these changes are not the result of disordered secretions from the walls of the urinary bladder, the urine being secreted normally, but undergoing in its course through the urinary passages a kind of fermentation, which induces decomposition of the urea and the formation of carbonate of ammonia.

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[*] "Leçons," 1859, vol. ii. p. 155.

[†] "Zeitschr. f. Rat. Med.," t. iv. p. 93.

[‡] Donders, "Phys.," 485.

[§] Thudichum, "On the Pathology of the Urine," p. 26, 1858.

[‖] "Phys. Untersuch.," 1820.

391. The *Specific Gravity* comes to be a very important character in various morbid conditions of the urine; and it is therefore desirable to estimate it correctly. This also is of course subject to the like causes of variation; since, when the same amount of solid matter is dissolved in a larger or smaller quantity of water, the specific gravity will be proportionably lower or higher; or, the quantity of water remaining the same, an increase or diminution in the amount of solid matter will raise or lower the specific gravity. It has been commonly supposed that the amount of solid matters in the urine bears such a constant ratio to its specific gravity, that the former may be approximatively deduced from the latter; this, however, is now ascertained to be by no means the case.† Still, the determination of the specific gravity is of sufficient importance for diagnostic purposes, to make it desirable to possess an average standard, as nearly approaching to accuracy as circumstances will permit. The average, according to Dr. Prout, in a healthy person, taking the whole year round, is about 1020; the standard rising in summer (on account of the greater discharge of fluid by perspiration) to 1025; and being lowered in winter to 1015. Simon, however, states the average specific gravity at no more than 1012. Dr. Roberts‡ observed the specific gravity of his own urine, while in a healthy state, to vary from 1001 to 1036. That the specific gravity does not bear any constant relation to the quantity discharged, has been shown by Dr. Hammond; who noticed that, although the afternoon and evening urine was most abundant, its specific gravity was very high, in consequence of its containing a large proportion of solid ingredients. The specific gravity of the urine probably depends mainly, in each individual case, upon the amount of azotized solids and of aqueous fluids habitually ingested, allowing for the portion of the latter that is dissipated by cutaneous ex-

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* Hermann, however, was unable to observe any alteration in either the quantity or quality of the urine secreted after section of the nerves accompanying the renal arteries. —"Canstatt's Bericht," 1862, p. 128.

† See Lehmann's "Physiological Chemistry" (Cavendish Society), vol. ii. p. 436.

‡ "Edinb. Med. Journ.," 1860.

halation; and it will also vary with the period that has elapsed since the last introduction of liquid into the stomach. From these and other causes, the amount of solid matter in 1000 parts of urine may vary from 20 to 70 parts; and hence the various recorded analyses of this liquid present very wide diversities in the proportions of its solid constituents.[*] These discrepancies, however, being chiefly due to the fluctuating amount of water, become very much less (as Simon pointed out) when we calculate the proportion which each principal component bears to 100 of solid residue; as is shown in the following Table:—

	Berzelius.	Lehmann.	Simon.	Marchand.
Urea	45·10	49·68	33·80	48·91
Uric acid	1·50	1·61	1·40	1·59
Extractive matter, Ammonia-salts, and Chloride of Sodium	36·30	28·95	42·60	32·49
Alkaline Sulphates	10·30	11·58	8·14	10·18
Alkaline Phosphates	6·88	5·96	6·50	4·57
Phosphates of Lime and Magnesia	1·50	1·97	1·59	1·81

We shall presently find the causes of some of the variations even here shown, to lie in the nature of the ingesta, and in the amount of exercise taken by the individual.—The following Table[†] will show the usual constituents of healthy urine, and the quantities excreted in 24 hours:—

Urinary Constituents.	Average quantity excreted in 24 hours, in grains.	Average quantity excreted for each 1 lb. avoird. of body-weight (estimating this at 150 lbs.), per diem, in grains.
Urea	512	3·5
Uric Acid	8·5	0·057
Hippuric Acid	15	0·1
Creatinine	15	0·1
Xanthine	Traces.	—
Phenylic		
Taurylic Acids.		
Damaluric		
Damolic		
Pigment		
Mucus	7	—
Inorganic Salts (varying greatly in their relative proportions according to the nature of the food, and composed of)	140 to 380	0·933 to 2·53
Sulphuric Acid	17·34 to 41·14	0·115 to 0·27
Phosphoric Acid	31 to 79	0·207 to 0·526
Chlorine	51·87 to 173·2	0·345 to 1·154
Potash	26·36 to 107·7	0·175 to 0·718
Soda	79·75 to 171·0	0·531 to 1·14
Lime	2·33 to 6·36	0·015 to 0·042
Magnesia	2·53 to 4·21	0·016 to 0·028
Silicic Acid	Traces.	—

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[*] It is remarked by Lehmann (Op. cit., p. 447), that the urine of the French is poorest in solid constituents, especially in urea and uric acid, and that of the English the richest, that of the Germans being intermediate between the two; the ratio in each nation being in conformity with the proportion of animal food entering into its ordinary diet.

[†] Chiefly drawn up from the works of Parkes, "On the Urine," 1860, Lond.; Thudichum, "On the Pathology of the Urine," 1858, Lond.; and Neubauer and Vogel, "On the Urine," Lond. 1863, New Sydenham Society's Translation; to which excellent treatises the reader desirous of further information is referred.

It is difficult, if not impossible, to determine the exact mode in which the acids are distributed amongst the bases, but the Chlorides and Phosphates seem to be eliminated in the following proportions :—

		Grains in 24 hours.	
Chloride of Sodium	about	150	
Chloride of Ammonium	,,	35	
Phosphate of Magnesia	,,	5	Lehmann and Kletzinsky.
Phosphate of Lime	,,	10	

The relation between the two last is reversed by Neubauer.

The urine contains, in addition, free carbonic acid, oxygen, and nitrogen gases; together with a certain and not inconsiderable quantity of extractive matters, consisting of substances whose nature has not been accurately determined, as in the case of those containing sulphur and phosphorus, the substance termed Oxide of Omichmyl by Scharling (which is apparently of a resinous nature), and others. The aggregate amount of the extractives is estimated by Dr. Parkes at 154 grains per diem, and constitutes a wide and very important field for future investigations. It will thus be seen that the total quantity of solid material eliminated by the kidneys does not fall far short of 900 grains in the 24 hours for a healthy adult man weighing 150 lbs., the proportion of organic compounds being about 550 grains, and of inorganic about 300 grains.—Under the head of constituents not constantly, or not certainly present, or perhaps present only in disease, may be enumerated albumen, fibrin, sarkin, grape-sugar, lactic and oxalic acids, fatty substances, biliary colouring matter, salts of the biliary acids, allantoin, leucin, and tyrosin, cystin, inosite, taurin, hæmatin, pus, spermatozoa, carbonate of ammonia, phosphate of ammonia, and magnesia and sulphuretted hydrogen,* besides various substances consumed as food and eliminated by the kidneys, as the colouring and odorous matters of various vegetables and certain metals.

392. The most important of those organic constituents of the Urine, whose formation has already (§§ 326, 327) been traced to the metamorphosis of the azotized components of the tissues and of the blood, is evidently that which, from its being the principal source of the characteristic properties of the secretion, is termed *Urea*.† Its chemical relations are stated to be best explained upon the hypothesis that it is the diamide of carbonic acid.‡ This substance, as already mentioned (§§ 141, 160), exists preformed in the blood in the proportion of from 2 parts (in renal venous) to 4 parts (in renal arterial blood) in 10,000. It possesses the power of dialyzing through animal membranes with remarkable facility, almost equalling carbonate of potash in this respect.§ The absolute quantity of urea eliminated in 24 hours, varies with age, season, weight of body, food, and occupation, and has been made a subject of examination by various chemists. The subjoined Table‖ gives the results of some of the more recent analyses :—

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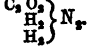
* v. Gorup-Besanez, "Phys. Chemie," p. 510.

† Urea ($C_2 H_4 N_2 O_2$) contains 46·7 per cent of nitrogen, and is isomeric with cyanate of ammonia ($N H_4 O, C_2 NO$), and with carbamide  $\left.\begin{matrix} C_2 O_2 \\ H_2 \\ H_2 \end{matrix}\right\} N_2$.

‡ "Miller's Chemistry," vol. iii. p. 615.

§ See Weikart, "Wagner's Archiv d. Heilkunde," 1862, p. 119.

‖ Partly taken from Dr. Day's "Physiolog. Chemistry," 1860.

	Age in Years.	Weight in lbs. avoird.	Grains of Urea excreted in 24 hours.	Proportion of Urea excreted to 1000 parts of body-weight in 24 hours.	Ditto for every 1 lb. of body-weight.	
Girl	3½	35·7	199·8	0·79	5·67	Scherer.
Boy	7	49·2	281·8	0·81	5·72	
Man	22	137·8	415·8	0·43	2·94	
Man	38	153·7	459·2	0·42	3	
Boy	3	29·8	207·7	1·03	6·96	Rümmel.
Boy	4	31·7	240·2	1·08	7·57	
Girl	5	36·9	280·2	1·08	7·59	
Youth	18	129·1	562·1	0·62	4·36	
Man	31	163·7	604·9	0·51	3·69	
Man	65	127·9	295·2	0·33	2·31	
Boy	3	35	65·7	0·53	1·9	Bischoff.
Youth	16	107	305·8	0·41	2·85	
Girl	18	145	310·9	0·30	2·14	
Woman	43	107	389·9	0·28	3·63	
Man	45	237	579·5	0·35	2·44	
Man	42	196	519	—	2·73	Ed. Smith.

From an examination of such tables as this we may draw the conclusions, that the average quantity of urea discharged by a man of good bodily health, is about 500 grains per diem; and that children of from 3 to 7 years of age excrete, proportionately to their weight, about double the quantity of urea per diem excreted by men in adult life, the quantity still further diminishing in old age.

Season.—Dr. Ed. Smith,* in the course of the year, found that the daily quantity (in himself) varied from 219 to upwards of 700 grains, the average upon the whole being 519 grains. The proportion to each 1 lb. of body-weight was, on the whole average, 2·76 grains. But in experiments in prisons, either with or without hard labour, the proportion varied from 3·72 to 5·82 grains to each 1 lb. of body-weight; so that he is of opinion that the relative proportion is of no scientific value. There was increase with diminished temperature and with increased atmospheric pressure, and hence variations in the relations of these two agencies varied the results. The increase in the elimination of urea with cold was often deferred until the following day. The period of elimination is not that of production, and whatever increases elimination of urine increases that of urea also.

Period of the day.—The greatest hourly elimination of urea, in Dr. Smith's experiments, occurred after the breakfast and tea meals; whilst it was least during the hours of the night and early morning.

Sex.—According to Dr. Parkes, the quantity of urea excreted every 24 hours, for 1 lb. of body-weight is, for men, about 3½ grains; for women, about 3 grains. During menstruation, according to Beigel, the excretion of urea diminishes, but subsequently it is increased.

Food.—Variations in the quantity and quality of the food occasion great differences in the proportion of the urea. The following Table gives the results of some of the best observers:—

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* "Proceedings of the Royal Society" for May 30, 1861, a private communication.

	Lehmann.*	Haughton.†	Warnecke.‡		Kölliker and Franque.§
			Man.	Woman.	
I. Mixed Diet	501·76	576	520	414	586·7
II. Highly Animal Diet . .	821·37	—	—	—	1420
III. Vegetable Diet . . .	347·10	394	389·6	310	447·7
IV. Non-azotized Diet . .	237·90	—	—	—	262·48

The quantity of urea always increases after food, attaining its maximum usually about the 3rd or 4th hour. When an animal is fed on fat and water exclusively, or on starch and fat, with a very small admixture of albuminous compounds, or on sugar, the excretion of urea falls even below the proportion found in absolute starvation,|| apparently because when no food, or an inadequate quantity of flesh-food, is given, the animal consumes some of its own flesh in order to maintain its temperature, and thus more Nitrogen is eliminated than when fat is supplied; for this, by combining with the Oxygen, keeps up the temperature, and spares the tissues of the animal. Genth¶ has shown that an increase in the quantity of water drank was followed by a marked increase in the quantity of urea eliminated, and this especially if the water were taken, not between, but at, meal-times. Certain substances consumed with the food increase the quantity of urea excreted; amongst these are Urea itself and Uric Acid, common Salt (Voit), Phosphoric Acid (Bocker), Glycine, Guanine, Theobromine, Cubebs, and Cantharides.** On the other hand, it is diminished by Digitalis, Arsenic, Turpentine, and Alcohol.

Exertion.—With violent labour, as that of the treadwheel, there was in Dr. Ed. Smith's experiments only an increase of 19 grains daily over that of light labour. On Sunday there was an increase with increase of food; but in prisoners without variation of food, with spare systems, and with increase in the fæces, there was a decrease. Similar results have been obtained by Voit,†† who, in consequence of the very small differences which he found to occur in the quantities of urea eliminated in fasting animals (Dogs) with and without work, believes that such slight increase of urea as really occurs after severe labour, is due to increased thirst and ingestion of water, together with increased rapidity of the movements of the heart and lungs. Lehmann's experiments ‡‡ showed also that no increase of urea took place in those engaged in active exercise.

Frequency of Micturition.—Kaupp §§ has shown that with increased frequency of micturition there is an increase in the quantity both of urine and of urea discharged in 24 hours.

Disease.—The amount of urea eliminated increases in the early stages of nearly all acute diseases,—meningitis, pneumonia, typhus, &c.,—indicating the rapid disintegration of the nitrogenous tissues, and coinciding with the period during which increased heat of skin is usually complained-of.

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* Lehmann, "Phys. Chem." (Cav. Soc. ed.), vol. ii. pp. 450-52.

† Haughton, "Dublin Quart. Journ.," 1859.

‡ "Dub. Med. Press," 1859.

§ Vierordt, "Phys.," 1860.

|| Ludwig, p. 381, vol. ii.

¶ "Untersuch. über den Einflüss des Wassertrink. auf den Stoffwechsel," 1856.

** v. Gorup-Besanez, "Physiolog. Chem.," p. 540, 1862.

†† Henle and Meissner, 1860, p. 373.

‡‡ "Archiv des Vereins für Wissenschaft. Heilkunde," vol. iv. p. 484, 1860.

§§ "Archiv f. Phys. Heilk.," 1856.

During convalescence it gradually subsides, and may even fall below the normal amount. The proportion appears to be remarkably diminished in some forms of hepatic disease. Thus Frerichs,* in a case of acute atrophy of the liver, found no trace of urea in the urine, but in its place leucin and tyrosin. In another case, recorded by Vogel, of cancer of the liver, scarcely one-fourth of the normal quantity of urea was found in the urine; and Heller has shown that the proportion of urea is diminished in chronic nervous affections, and in anæmiæ, however produced.†

393. Next in importance to urea among the organic products of the metamorphosis of the azotized constituents of the tissues or of the blood, but ordinarily bearing a very small proportion to it (1 : 50 or 60) in quantity, is *Uric Acid* ($C_{10} H_4 N_4 O_6$). This compound contains 33 per cent of nitrogen. The variations in the daily quantity eliminated are considerable; and, according to Ranke, whilst in great measure independent of differences in age, sex, height, weight, or temperature, stand in close relation with the ingestion of food, diminishing with abstinence, and materially rising soon after meals. Prof. Haughton found the average quantity eliminated by those consuming animal food to be 4·55 grains per diem, whilst vegetarians discharged only 1·48 grains. It is diminished after the use of Alcohol (Hammond), and after the administration of Quinine (Ranke), and is totally absent when large draughts of water have been taken (Genth). It is increased after the free use of Tobacco (Hammond), and after the consumption of certain substances introduced into the food, as Glycin. A marked increase has been observed in intermittent fevers, in Leukæmia, in Peritonitis, Phlebitis, and some chronic renal and spinal affections. Uric Acid is found in the spleen-pulp in considerable quantities, and also in the lungs, liver, pancreas, and brain; in the juice of muscles, and in small quantities in the blood (Garrod) in the form of an acid urate of soda or ammonia.‡ It seems, therefore, to be very generally present where active interstitial changes are taking place. The *precipitation* of Uric acid (usually in combination with potash, soda, and ammonia, and perhaps sometimes with lime), which frequently takes place on the cooling of the urine, must not be regarded as indicative of the presence of an unusual amount of this substance; since it may depend upon other conditions. It seems to have been clearly proved by Dr. Bence Jones,§ that there is no relation whatever between the *acidity* of the urine, and the *absolute amount* of Uric acid which it may contain; for in the urine which is most acid, and which deposits the largest uric-acid sediment, very little uric acid may really exist; whilst that which contains most uric acid may hold it in perfect solution, and may have but a feeble acid reaction. The main cause of the deposit of Uric-acid sediments, is doubtless the presence of some other acid; for the addition of any acid to healthy urine passed soon after food, is always sufficient to produce it. But the deposit takes place less readily if the temperature of the fluid be high, since the solvent power of the acid phosphate of soda is then more strongly exerted; so, on the other hand, a deposit often takes place in urine which would not otherwise exhibit it, through an unusual reduction in its temperature, as by exposure to the cold air of a sleeping-

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* "Deutsch-Klinik," 1855, p. 31.

† Gmelin, vol. viii. p. 325.

‡ Thudichum, "Pathology of the Urine," p. 97.

§ See his 'Contributions to the Chemistry of the Urine,' in "Philos. Trans.," 1849.

room in the winter. Again, the deposit of uric-acid sediment is favoured by concentration of the liquid, which thus augments the proportion of the urate to the water, and at the same time intensifies the acid reaction; and thus urine whose constituents are otherwise normal, may throw down a copious deposit of this kind, merely from deficiency of water; whilst an unusual amount of uric acid may be really present without being deposited,—the urine, too, exhibiting its ordinary acidity,—if the proportion of water be large. Thus the uric-acid sediment may be regarded as dependent upon three concurrent conditions:—(1) Decrease of temperature; (2) Increased proportion of uric-acid compound to the water, positively or relatively; (3) Increased acidity of the urine. Sometimes one condition is most influential, sometimes another; but they are all usually concerned in some degree.—There are many diseases, especially those of a febrile nature, in which the presence of an *excess* of uric acid is a very marked symptom; there is often, at the same time, a reduction in the proportion of urea; and thus it would seem that, with perhaps an augmented tendency to disintegration of the tissues, there is an incapacity for the performance of that higher process of oxidation, which is requisite for the genesis of urea; so that a larger proportion of the products of the 'waste' passes-off in the state of uric acid, as in animals whose respiration is feeble. — The proportion of *Hippuric Acid* ($C_{18}\,H_8\,NO_5 + HO$) present in the urine appears to be in great measure dependent upon the nature of the food and upon the amount of exercise. According to the researches of Weissmann and Thudichum, it amounts to between 30 and 40 grains per diem on a mixed diet. On a purely animal diet, it falls to about 12 grains per diem; whilst it rises considerably when vegetables alone are consumed. As might be anticipated, therefore, a large quantity of this acid is constantly present in the urine of Herbivora, but only traces exist in that of Carnivora. Both Mack and Roussin found that Horses at rest pass much urea and little Hippuric acid; but when at work, the quantity of Hippuric acid equalled or exceeded that of urea, the absolute quantity of the latter undergoing a diminution equal to the increase of the Hippuric acid. As urea is one of the ultimate products of oxidation in the body, whilst Hippuric acid is very imperfectly oxidized, it would seem that during violent exertion the due oxidation of the secondary nitrogenous compounds produced by the disintegration of the tissues is interfered with, perhaps by the diversion of the oxygen to form carbonic acid, the quantity of which has been shown by Dr. Ed. Smith to be so notably increased by all kinds of muscular exertion; or we may, with more probability, suppose that the lungs are unable to eliminate the whole of the carbon of the disintegrated tissues in the form of CO_2, and that a part of the carbon is consequently discharged by the kidneys in the form of the richly-carbonized compounds, Hippuric or Benzoic acids. The quantity of Hippuric acid eliminated can be greatly increased by the administration of Benzoic, Succinic, Cinnamic, or Kinic acids, or of Oil of bitter almonds.* The transformation of Benzoic into Hippuric acid appears to take place at the liver, as it does not occur in jaundiced patients, or in dogs in whom the ductus communis choledochus has been tied, the Benzoic acid then passing-off unchanged.—*Creatine* and *Creatinine* may be obtained by the action of Chloride of Zinc on concentrated urine; but the researches of Heintz* have shown that no Creatine is present in fresh urine, that which was formerly obtained being in fact produced by the decomposition of the Chloride of Zinc compound, the Creatinine of which takes up water and is converted into Creatine.† The quantity of Creatinine daily eliminated by a healthy man, living on a good mixed diet, was found by Neubauer to vary from 9 to 20 grains. Creatinine is the most powerful organic base in the body. Creatine can be readily converted by boiling with Baryta water into Sarcosine and Urea.‡—Scherer and Neubauer found a small quantity of *Xanthine* was usually present in human urine. From 600 lbs. of Urine the latter obtained 15½ grains, and from the same quantity 247 grains of Benzoic acid.—The colouring matter of the urine has been shown by Dr. G. Harley to proceed from the Hæmatin of the blood. He terms it Urohæmatin. It contains iron, is insoluble in the strongest mineral acids, but dissolves in solutions of ammonia, potash, and soda, and in alcohol, ether, and chloroform. He has resolved Urohæmatin into a resin and two other substances. Schunck and Carter§ consider the colouring matter of the urine to be a modification of Indigo, and believe that the terms employed by Heller‖ of Uroglaucin, Urrhodin, and Uroxanthin, indicate respectively Indigo-blue, Indigo-red, and Indican. All these substances, as well as those included under the general term of Extractives, contain considerable proportions of carbon, whilst they are comparatively poor in nitrogen; so that their increase will be favoured by an excess of carbonaceous food, an imperfect action of the liver, and a low degree of respiration; whilst, on the other hand, a highly-azotized diet, especially if combined with active exercise, will tend to their reduction.—The odour of the urine appears to be due to the presence of minute quantities of the volatile acids, termed by Stadeler Phenylic (or Carbolic, $C_{12} H_5 O_1$, HO), Taurylic ($C_{14} H_8 O_2$), Damaluric ($C_{14} H_{11} O_3$, HO), and Damolic, the composition of which last is unknown.

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* See Matschersky, "Virchow's Archiv," 1863, p. 528.

394. Besides its organic materials, the Urine contains a considerable amount of *Saline* matter; the excretion of which, in a state of solution, appears to be one of the principal offices of the Kidney. Various saline compounds are being continually introduced with the food; and others are formed within the system, by the oxidation of the Sulphur and Phosphorus of the tissues or of the food, and by the combination of the sulphuric and phosphoric acids thus formed, with alkaline and earthy bases which the food may contain, usually in a state of combination with weaker acids which are otherwise disposed-of. Thus the saline compounds found in the urine are to be regarded as partly proceeding from the retrograde metamorphosis of the materials of the tissues, after these have served their purpose in the economy, and partly from that of such components of the food as, being superfluous, do not undergo organization. But the Kidney also serves as the channel for the elimination of saline compounds introduced into the system *per se*; these being sometimes

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[*] Vogel and Neubauer, "On the Urine," New Syd. Soc. Transl., 1863, p. 18.

[†] Creatinine $C_8 H_7 N_3 O_2 + 4HO$ becoming Creatine $C_8 H_{11} N_3 O_6$.

[‡] Creatine $C_8 H_{11} N_3 O_6$ becoming Urea $C_2 H_4 N_2 O_2$ and Sarcosine $C_6 H_7 NO_4$.

[§] "Memoirs of Manchester Med. Soc.," vol. xiv. p. 293. See also Kletzinsky, "Heller's Archiv," vol. vi. p. 414.

[‖] "Archiv f. Chem. und Mikroskop.," band ii. pp. 161–173.

normally present in the body, but ingested in too large an amount, as is often the case with common Salt; whilst, on the other hand, they may be altogether foreign to the composition alike of its solids and its fluids. —The *Alkaline Sulphates* usually constitute, as we have seen (§ 391), at least 10 per cent of the whole solid matter of the Urine. Being always in solution, however, they never make their presence known by the formation of sediments, and are only to be detected by chemical tests. The causes which influence their amount have been carefully studied by Dr. Bence Jones; who has shown that they vary (like urea) with the amount of food ingested, and with the degree of nervo-muscular activity put-forth; as might be anticipated from the fact, that, under ordinary circumstances, the sulphuric acid is entirely formed within the system, by the oxidation of the sulphur of the protein-compounds, the bases being furnished by the alkaline carbonates or phosphates of the blood. When sulphuric acid or soluble sulphates are taken into the system *per se*, they partly find their way out of it by the Kidneys; the proportion of sulphuric acid in the urine being for a time augmented, although the increase is not considerable until some hours have elapsed after the introduction of these substances into the stomach.*—The amount of *Alkaline Phosphates* in the Urine is usually about half that of the alkaline sulphates. The acid of these also is ordinarily generated within the system, by the oxidation of the phosphorus originally introduced in the protein-compounds; and thus, as in the case of the sulphates, the quantity of them which is excreted by the urine bears a certain relation to the amount of these compounds ingested as food, and also to the amount of muscular tissue which has undergone disintegration by exercise. But it further appears that there is a special relation between the quantity of the alkaline phosphates in the urine, and the amount of disintegration of the *nervous* tissue; as might have been suspected from the fact, that this tissue is distinguished by the very large proportion of phosphorus, united with fatty acids, which it contains. And a marked increase of these salts is observed in those inflammatory diseases of the brain, in which there is reason to believe that an unusually-rapid disintegration of its texture is taking place.† —The *Earthy Phosphates* usually bear but a small proportion to the Alkaline; but their presence in the urine comes to be of great importance with reference to the precipitates which they form in particular conditions of that secretion. From the researches of Dr. Bence Jones (loc. cit.) it appears, that the quantity of these phosphates in the urine chiefly varies with the amount of them contained in the food, into many articles of which they enter largely; but he has also ascertained that their formation within the system is determined by the presence of their bases; for if any earthy salt, a little chloride of calcium or sulphate of magnesia for instance, be taken into the system, the quantity of earthy phosphates in the urine undergoes an increase. The small quantity of carbonate of lime taken into the system with the food, or set-free by the slow disintegration of the osseous tissue, is probably excreted in Man almost entirely in the form of phosphate; although of the much larger amount ingested by herbivorous animals, a considerable proportion is excreted in the urine in its original state. The Earthy Phosphates, although insoluble in water, are soluble in all acid liquids; and they are held in solution in Urine, like the urates, by the acid phosphate of soda. Their precipitation in an alkaline state of the urine is owing to the want of this solvent, not to an excess in their production; for, as Dr. Bence Jones has pointed-out, that excess of alkaline and earthy phosphates in the urine which constitutes the true 'phosphatic diathesis,' is generally coincident with a highly-acid state of the urine.—The only other inorganic saline constituent of the Urine, whose quantity gives it importance, is *Chloride of Sodium.* By far the larger proportion of this is doubtless derived directly from the food; but little being furnished by the disintegration of muscle, which will set-free potash rather than soda. The amount eliminated by the urine is consequently subject to great variation, it being the function of the Kidneys to remove whatever is superfluous, so as to prevent the blood from becoming overcharged with this substance. Of the chloride of sodium introduced as food, a part appears to undergo decomposition in the system, whereby hydrochloric acid is furnished to the gastric fluid, and soda to the bile; much of this acid, however, must reunite with its base in the alimentary canal, so that the chloride of sodium thus regenerated will be absorbed with the products of the digestive operation.—Although *Nitric Acid* can scarcely be regarded as a normal constituent of the Urine, yet the investigations of Dr. Bence Jones* appear to show that it is formed by a combustive process within the body, whenever ammoniacal salts are introduced into the system; its amount, however, being very small. He has also found that it is generated after the ingestion of small quantities of urea; a fact which affords some confirmation to the doctrine of Frerichs (§ 388), that urea may undergo decomposition into carbonate of ammonia, whilst still circulating in the current of blood.—The presence of *Oxalic Acid* in the urine (in combination with Lime) has been usually regarded as a pathological phenomenon, consequent upon an irregular performance of the retrograde metamorphosis of the tissues; but there can be no doubt that it may also result from the presence of soluble salts of oxalic acid in certain articles of vegetable food.†—The Gases found in the Urine have been examined by Planer‡ and Bernard.§ Planer found in one instance 7, and in another 16 per cent of gas. The following Table gives the percentage composition of the gases obtained:—

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* Dr. Bence Jones in "Philosophical Transactions," 1849.

† See Dr. Bence Jones's valuable series of Papers in the "Philosophical Transactions" for 1845, 1847, and 1850, and in the "Medico-Chirurgical Transactions" for 1847 and 1850.—It is curious to observe, that whilst the increase in the alkaline phosphates in Inflammatory affections of the nervous centres is very marked, there appears to be a positive diminution of them in Delirium Tremens. A certain allowance must be made, however, for the abstinence from food, which will of itself occasion a reduction in the quantity excreted.

	Planer.		Bernard.
Carbonic Acid . . .	84·2	92·3	78·81
Nitrogen	15·2	7·2	18·64
Oxygen	0·5	0·5	2·55
	100	100	100

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* "Philosophical Transactions," 1851.—It is right to state, however, that this doctrine has been called in question by some eminent authorities, who deny the validity of the test for nitric acid employed by Dr. Bence Jones.

† See Dr. Golding Bird on "Urinary Deposits."

‡ v. Gorup-Besanez, "Physiolog. Chem.," 1862, p. 526.

§ "Leçons," vol. i., 1859, p. 347.

About one-third of the carbonic acid was combined, the remaining two-thirds were free.

395. The ordinary *acid* reaction of the Urine appears to be due, not to the presence of any free acid, but to the conversion of the *basic* phosphate of soda into the *acid* phosphate, by the subtraction of a part of the base, which occurs when uric, hippuric, lactic, or other free acids come into contact with the former substance. There is no adequate reason to believe, that, in the healthy state, there is ever any other cause than this; although in morbid urine, free organic acids are almost certainly present.* It has been shown by the researches of Dr. Bence Jones,† with whose observations those of Roberts‡ generally agree, that the acid reaction is far from being constant in its degree, even when an ordinary mixed diet is steadily employed; for that it varies at different periods of the day, increasing and decreasing *inversely with the acidity of the stomach* (§ 85). Thus the acidity of the Urine decreases soon after taking food, whilst that of the Stomach is increasing, and attains its lowest limit about three to five hours after a meal, when, therefore, absorption is being most actively performed. An alkaline reaction is often observed in the urine at this period, which, according to Dr. Roberts, is due to the presence of fixed alkali; § this occasions a precipitation of earthy phosphates, rendering the urine turbid, though the quantity of uric acid at this period is always large. The acidity then gradually increases, whilst that of the stomach is decreasing; and attains its highest limit after a fast of some hours, when the stomach is quite empty, and its secretion neutral. If no food be taken, the acidity does not decrease, but remains at nearly the same point for ten or twelve hours. When *animal* food was alone employed, the diminution of the acidity after a meal was more marked and continued longer than when a mixed diet was eaten (apparently on account of the greater demand for acid in the stomach); and the acidity did not rise quite so high after fasting, as with a mixed diet. On the other hand, when the diet was purely *vegetable*, the diminution of the acidity of the urine was never such as to render it absolutely alkaline, although its acidity was reduced to the point of neutrality; and the increase of its acidity after fasting was sometimes very considerable, though by no means so marked as the decrease of alkalescence.—These diurnal variations in the acidity of the urine make it highly probable, that corresponding variations occur in the alkalescence of the blood; such diurnal variations being produced by the quantity of acid separated from it, and poured into the stomach for the purpose of dissolving the food. The introduction of dilute sulphuric acid into the stomach, even in large doses, was not found to produce any decided change in the acidity of the urine; the only perceptible effect being a slight diminution of the decrease which takes place after taking food, and a slight augmentation of the increase after fasting. On the other hand, the use of liquor potassæ in large doses lessens the acidity of the urine, preventing it from rising after fasting to the height it would otherwise attain, and increasing its alkalescence after a meal; but it does not render the urine by any means constantly alka-

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* See Prof. Lehmann's "Physiological Chemistry" (Cavendish Society's ed.), vol. ii. pp. 404-406.

† "Philos. Transact.," 1849.

‡ "Memoirs of Manchester Phil. Society," 1859.

§ Ibid.

line, nor does it hinder the variations produced by the state of the stomach from being very evident. Tartaric acid in large doses temporarily increases the acidity of the urine, causing it to rise considerably higher than usual after a fast, but not preventing that which is passed a few hours after food from becoming alkaline. Tartrate of potash in large doses, on the other hand, has a marked effect in rendering the urine alkalescent; still, it does not prevent the usual recurrence of the acidity some hours after a meal.—The Urine of Herbivorous animals is almost invariably *alkaline;* partly because their food contains a large quantity of alkaline and earthy bases, in combination with citric, tartaric, oxalic, and other acids, which are decomposed within the system; and partly because the amount of sulphuric and phosphoric acids, generated as products of the oxidation of the elements of the tissues or of the surplus-food, is not sufficient to neutralize them. Such is the condition which occasions the alkalinity of Human Urine, when a portion of the acid which would otherwise show a predominance is directed into another channel; and it is exaggerated in those states, in which, either from the irritating nature of the food, or from the irritable condition of the stomach, an undue quantity of acid is poured-out into that viscus; so that, its reaction being habitually acid, that of the urine becomes habitually alkaline. Such a state of the urine must be carefully distinguished, as Dr. Bence Jones has pointed-out,* from that in which the alkalescence is due to the presence of *volatile,* and not to that of *fixed* alkali; the difference being easily recognizable by the influence of the liquid upon reddened litmus-paper, for the restoration of its blue colour is permanent in the latter case, but only transitory in the former. The alkalescence due to the presence of volatile alkali is due to the decomposition of urea, whilst the urine is yet within the bladder, through the agency of morbid secretions of that viscus; and it disappears when this organ returns to its healthy state. On the other hand, the alkalescence from fixed alkali proceeds from disordered action of the stomach, which is usually connected with disorder of the general system; and it persists until this can be remedied. In both forms of alkalescence, there is a precipitation of earthy phosphates; but in the alkalescence from fixed alkali, the precipitate usually consists almost entirely of phosphate of lime; whilst in that from volatile alkali, the amorphous sediment of phosphate of lime is mingled with prismatic crystals of the phosphate of ammonia and magnesia. These precipitates may be obtained from healthy urine, by adding to it a solution of potash or of ammonia; and the decomposition of such urine, which begins to take place very soon after it leaves the body, gives rise to the same precipitation, by the production of carbonate of ammonia at the expense of its urea.

396. Thus, then, we have seen that the Kidneys serve as the special instruments for depurating the Blood of those *highly-azotized* compounds, which are formed in the system by the decomposition of the materials of the albuminous and gelatinous tissues, and also by that of the non-assimilated components of the food. We have seen also, that they serve for the removal of certain excrementitious compounds, of which *carbon* is a principal ingredient; and these, although normally present in but small amount, may undergo a marked increase in disease, especially when the

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* "Medical Times," Dec. 13, 1851.

liver is insufficiently performing its functions, or the respiratory process is obstructed. Further, we have been led to regard the Kidneys as the emunctory, not only for the superfluous water of the blood, but also for those saline compounds, which, having been introduced into the system or generated within it, in larger amount than is compatible with the normal constitution of the blood, or than is required for the reparation of the solids of the body, or for the production of its fluid secretions, are only fitted for elimination (§ 330). On this point a very elaborate series of researches was made by Wohler,[*] who showed that of the soluble salts taken into the circulation, those are most readily excreted which produce a determination of blood towards the kidneys, whereby an increased quantity of liquid is filtered-off through the outlet which they afford. This statement is to be extended from saline compounds, to such other soluble matters as are not eliminated by preference through other channels, or are present in too large an amount to find their way out thence with sufficient rapidity, as Sugar and Lactic acid. In like manner, too, the system makes an effort to free itself (so to speak) from various substances altogether foreign to it, which have been introduced into the circulating current by absorption, and which would be injurious if retained; the rate at which it does so, being in a great degree dependent upon the functional activity of the Kidneys (§§ 202, 203).

397. It is a most important fact, in a Dietetic and Therapeutic point of view, that the metamorphic process, of which the greater part of the constituents of the urine are the products, should be capable of retardation or of acceleration by the presence of other substances in the blood. The former appears to be the operation of *theine*, which is the active principle of Tea and Coffee; for according to the observations of Dr. Bocker[†] upon the former, and of Dr. Julius Lehmann[‡] upon the latter, a very decided decrease shows itself in the amount of urea and of phosphoric acid excreted in the urine, when these beverages are employed, as compared with the amounts of the same substances when the general regimen was as nearly as possible identical in other respects, but plain water was substituted as a drink. The difference is much greater in the case of Coffee than in that of Tea, amounting generally to as much as one-fourth; thus:—

	Urea.	Phosphoric acid.	Common salt.
	grammes.	*grammes.*	*grammes.*
H. S., without coffee, voided	31·298	4·421	9·865
,, with coffee from 1½ oz. of beans .	21·888	3·001	8·819
Difference	9·410	1·420	1·046

It appeared from other experiments, that neither caffeine nor the empyreumatic oil, separately administered, produce the same effect as coffee itself. Hence it appears that the use of Tea or Coffee, by retarding the 'waste' of the system, diminishes the demand for food, and makes a limited amount of it go further;[§] and this conclusion seems fully borne out by experience.*—The like results happen, according to Dr. Böcker,† under the use of small quantities of Alcohol frequently repeated; as much as 13⅓ grammes less urea being excreted daily, when a tea-spoonful of proof-spirit was taken seven or eight times a day, than when water alone was drank. It does not hence follow, however, that Alcohol can be used as advantageously for this purpose as Tea or Coffee; in fact, it may be doubted whether it is so much by diminishing the 'waste' of matter, as by interfering with the due elimination of its products, that Alcohol occasions a diminution in the weight of the urinary solids. For, although it does not appear to effect any marked diminution, but rather an increase in the elimination of certain forms of excrementitious matter which have been received back into the blood, and especially of the hydrocarbonaceous products (§ 288, VI.), yet very cogent evidence is supplied by the experience of Zymotic diseases, that the very same cause produces an accumulation of fermentible azotized substances in the blood (§ 52).—It seems not unlikely that the almost instinctive craving for Tobacco among a large proportion of mankind, arises out of its possession of a power of retarding the metamorphosis of the tissues; since we find that men, when supplied with this article, can far better sustain being put upon a short allowance of food, than when destitute of it.

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[*] Müller's "Elements of Physiology," translated by Baly, p. 589.

[†] "Archiv des Vereins für gemeinschaftlichen Arbeiten zur Forderung der Wissenschaftlichen Heilkunde," 1854.

[‡] "Annalen der Chem. und Pharm.," band lxxxvii.

[§] Dr. Ed. Smith ("Proceed. of Roy. Soc.," 1861) found the decrease in the elimination of urea after the use of tea (which had the greatest effect) and coffee, to be but slightly marked after the first day or two.

398. Of the substances that accelerate the metamorphosis of the tissues, and thus augment the solids of the urine, the Alkalies and their carbonates and Chloride of Sodium are those whose action is best known; these (with such of their salts as are formed by acids which are decomposed in the blood into the carbonic, such as the acetates, tartrates, and citrates) have a powerful solvent action on the albuminous compounds generally, and tend to break-up these compounds into simpler forms of combination. Hence it seems likely that their presence in the Blood in increased amount, will tend to hasten the retrograde metamorphosis of the tissues; their chemical force being exerted, not merely upon those which are already in a state of disintegration, but also upon those which, being disposed to degenerate, cannot exercise that resisting power which they possess when in a state of complete vital activity. The operation of Liquor Potassæ in health, in acute rheumatism, and in chronic diseases, has been carefully studied by Dr. Parkes;‡ and he has given satisfactory evidence that it causes an increase in the solids of the urine generally, but especially in the urea and in the amount of the sulphuric and phosphoric acids; thus clearly showing that it hastens the metamorphosis of some of the albuminous structures of the body. The increase was more marked, as might be expected from what has been just stated, in the cases of chronic disease, than in ordinary health. The following comparative Tables show the relative amounts before, during, and after, the employment of liquor potassæ, in (I.) a case of chronic Eczema, and (II.) a case of chronic Phthisis:—

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* Voit, from experiments with coffee on a *dog*, was led to a different result; and considers that this substance possesses but little influence on the excretion of urea. See Henle and Meissner, "Bericht," 1860, p. 347.

† Op. cit., 1853.

‡ "Brit. and For. Med.-Chir. Review," vols. xi., xiii., xiv.

	Solids.	*Urea.*	*Sulphuric Acid.*	*Phosphoric Acid.*
I.				
Before Liq. Pot.	660·1	371·5	29·2	10·6
During	689·6	454·5	33·5	15·4
After	527·2	372·8	29·0	10·9
II.				
Before Liq. Pot.	608·2	368·8	18·6	9·9
During	781·7	408·8	20·9	14·5
After	643·9	271·5	16·9	9·7

A similar Table has been given by Dr. Golding Bird,* of the entire constituents of the secretion passed during 24 hours, before and after the administration of three drachms of acetate of potash :—

	Before Medicine.	*After Medicine.*
Quantity of Urine	fl ℥ xvi.	fl ℥ xlvi.
Specific Gravity	1·025	1·017
Total Solids	416 grs.	782 grs.
Uric Acid	2·6 grs.	5·5
Urea	130·5 ,,	202·4
Other Organic Compounds	189·3 ,,	295·5
Soluble Salts	72·0 ,,	248·4
Insoluble Salts	21·6 ,,	32·2

The increase (176·4 grains) in the quantity of 'soluble salts,' is to be chiefly set-down to the account of the medicine taken-in; but the whole remainder of the augmentation seems fairly attributable to the increased metamorphosis.—It does not appear, however, that the excretion of the urinary solids is augmented by those 'diuretic' medicines, which cause a larger amount of liquid to be passed-off through the Kidneys, merely by determining an increased flow of blood to them. On the contrary, it would seem as if, by producing congestion and irritation, they sometimes interfere with the normal process of secretion; so that the quantity of solid constituents is actually decreased, notwithstanding the large augmentation in the watery part of the urine. This very important fact has been demonstrated by Prof. Krahmer,† who gives the following as the result of his observations upon the amounts excreted in 24 hours, after the administration of diuretics to persons in health:—

Medicine given.	*Total Solids in Urine.*	*Organic Compounds.*	*Inorganic Compounds.*
None	2·40 oz.	1·28 oz.	1·13 oz.
Juniper	2·12 ,,	0·94 ,,	1·18 ,,
Venice Turpentine	1·94 ,,	1·11 ,,	0·83 ,,
Squill	2·25 ,,	1·04 ,,	1·21 ,,
Digitalis	2·45 ,,	1·28 ,,	1·17 ,,
Guaiacum	2·43 ,,	1·38 ,,	1·05 ,,
Colchicum	2·32 ,,	1·36 ,,	0·96 ,,

Similar results have been obtained by Dr. Golding Bird.—It seems highly probable that the 'critical evacuations' of urine, as of sweat, or fæcal matter, on which the older physicians were accustomed to lay great stress, are really charged with noxious substances, of which the blood is thus depurated; and that great benefit would frequently arise in practice from the use of the 'alterative diuretics,' as suggested by Dr. G. Bird, where (as in chronic rheumatism, gout, &c.) there is reason to believe that a quantity of mal-assimilated matter exists in the system, of which it is

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[*] See his 'Lectures on the Influence of Researches in Organic Chemistry on Therapeutics,' in "Medical Gazette," 1848, vol. xlii. p. 230.

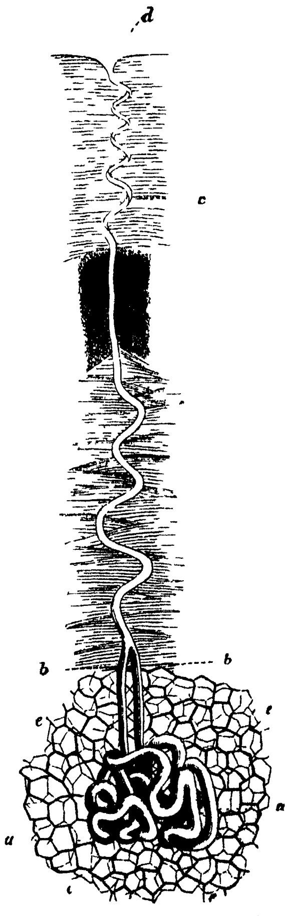
[†] "Heller's Archiv," Dec. 1847.

important to get-rid. In many such cases, indeed, clinical observation had already established the benefit derivable from such medicines, without affording the rationale of it.

4. *Of the Skin;—Cutaneous Transpiration.*

399. The Skin is the seat of various secretions,—as the Sebaceous, Ceruminous, and Odoriferous,—for each of which it is provided with special organs; but these have reference chiefly to its own protection, or to some other *local* purpose; and the only one which can be regarded as truly *excrementitious*, is the Transpiration of aqueous fluid, holding certain matters in solution. The elimination of this fluid from the blood is effected by the *Sudoriparous* glandulæ (Fig. 87), which essentially consist of long convoluted tubes (*a*, *a*), rarely single, but usually multiplied by repeated dichotomous subdivision (*b*), sometimes also giving-off short cæcal processes before their termination. These are seated rather beneath the Corium, in the midst of the subcutaneous adipose tissue, than in the substance of the skin itself. All the tubuli of each gland unite so as to form but one duct; and this passes upwards through the Cutis and Cuticle, in a somewhat corkscrew-like manner (*c*), to open upon the surface of the latter (*d*), which it usually reaches obliquely, so that the outer layer of the Epidermis forms a sort of little valve, which is lifted by the secreted fluid as it issues forth. These glandulæ are diffused in varying proportions over the entire surface of the body. According to Mr. Erasmus Wilson,* as many as 3528 of them exist in a square inch of surface on the palm of the hand; and since every tube, when straightened-out, is about a quarter of an inch in length, it follows that, in a square inch of skin from the palm of the hand, there exists a length of tube equal to 882 inches, or 73½ feet. The number of glandulæ in other [illegible] kin is sometimes greater, but is generally less than this; and, according to Mr. Wilson, about 2800 may be taken as the average number of pores

FIG. 87.



Sudoriparous Gland from the palm of the hand, magnified 40 diam.:—*a*, *a*, contorted tubes, composing the gland, and uniting in two excretory ducts, *b*, *b*, which unite into one spiral canal that perforates the epidermis at *c*, and opens on its surface at *d*; the gland is imbedded in fat-vesicles, which are seen at *e*, *e*.

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* "On the Management of the Skin," 3rd edit. p. 37.

in each square inch throughout the body. Now the number of square inches of surface, in a man of ordinary stature, is about 2500; the total number of pores, therefore, may be about *seven millions;* and the length of the perspiratory tubing would thus be 1,570,000 inches, or nearly 28 miles.

400. Although a separation of fluid by this extensive glandular apparatus is continually taking-place, yet this fluid, being usually carried-off in the form of vapour as fast as it is separated, does not ordinarily accumulate so as to become sensible. If, however, from the increased amount of the secretion, or from the condition of the surrounding air, the whole fluid thus poured-out should not evaporate, the residue forms minute drops upon the surface of the skin. Thus the Sudoriparous excretion may take the form either of *sensible* or of *insensible* transpiration; the latter being constant, the former occasional. When collected in the fluid state, sweat is a colourless liquid, possessing a peculiar odour according to the part of the skin from which it is obtained, and more or less turbid from the presence of sebaceous matter and epidermal scales, which constitute from 0·2 to 0·3 per cent of the whole amount of the excretion. Its reaction is usually acid, though Gillibert and Favre found that after protracted sweating it became neutral or even alkaline. Its acidity appears to be due to the presence of certain volatile acids, as the acetic, butyric, and formic; to which, and possibly to the metacetonic and capric acids, we are probably to attribute the sour smell which it possesses in some disordered states of the system. The substances which have been found to be constant constituents of the sweat are, water, fat, various volatile fatty acids in addition to those already mentioned, urea and inorganic salts, amongst the chief of which are the chlorides of sodium and potassium, the alkaline phosphates and sulphates, the earthy phosphates, and iron. That it is a true secretion, and not a mere transudate, is shown by the entire absence of albumen. Other constituents of the sweat, whose presence is not constant, or the nature of which has not been satisfactorily determined, are, the salts of ammonia, of lactic acid, and of the hydrotic acid of Favre, and certain pigmentary substances of various shades. In disease, uric acid, grape-sugar, albumen, and biliary colouring matters, have been found; and when taken with the food, benzoic acid (partly converted into hippuric), succinic, cinnamic, and tartaric acids, with iodine and iodide of potassium, have been recovered in the sweat. Funke calculates that about 11 grains of nitrogen are daily eliminated by the skin through the desquamation of the epithelial scales. He also found urea (the presence of which was first observed in the sweat by Dr. Landerer*) to be a constant constituent. In one experiment, the entire quantity of perspiration for the whole body for 1 hour, being 3320 grains, 6½ grains were found to be present. If the secretion had continued at the same rate for 24 hours, 157½ grains of urea would have been eliminated, containing 73½ grains of nitrogen. Under ordinary circumstances, however, it is probable that a very much smaller quantity is thus eliminated. From the general uniformity in the proportion of solids to 100 parts of sweat, observed by Funke, it is obvious that, with an increase in the quantity of fluid excreted by the skin, there is also an augmented excretion of solids; and to the deficiency which is thus produced in the salts of the blood may be partly assigned the debilitating effects of profuse perspirations. Other causes, however,

* "Heller's Archiv," band iv. p. 196.

probably concur in producing those effects. Thus the great fatigue which is experienced as a consequence of muscular exertion in a heated atmosphere, may fairly be set down to the diminished activity of the respiratory process at high temperatures (§ 316, I.), and the colliquative sweating of hectic fever is obviously not a cause but a consequence of, though it may also react upon and increase, the debilitated state of the general system. The proportion of solid matter contained in different specimens differs very greatly; thus, according to Anselmino, it varies between 5 and 12·5 parts in 1000; the observations of Favre* give 4·43 parts per 1000 as the proportion contained in nearly nine gallons which he had collected; whilst those of Schottin† raise it as high as 22·4 parts per 1000, of which, however, 12 parts consisted of epithelium and insoluble matters.

401. The entire amount of fluid which is 'insensibly' lost from the Cutaneous and Pulmonary surfaces was estimated by Seguin at 18 grains per minute; of which 11 grains pass-off by the skin, and 7 by the lungs. Funke,‡ with two students, made numerous experiments upon the amount and characters of the Sweat secreted from the hand and forearm under different circumstances. In these experiments the arm was enclosed in a caoutchouc bag, and each experiment lasted for one or two hours. It was found that the largest quantity of sweat obtained from the forearm and hand under favourable circumstances, in 1 hour, was 740 grains, which would, in 24 hours, supposing the secretion to continue at the same rate, amount to about 2½ lbs. But, from accurate measurements, Funke ascertained that the ratio of the superficies of the forearm and hand to that of the body generally was as 1 : 17; so that if the perspiration took place continuously and at the same rate from the whole surface of the body, upwards of 42 lbs. might be discharged in 24 hours. On the other hand, the minimum quantity excreted by the hand and forearm was 48 grains per hour, which would amount to 1152 grains in 24 hours, and this, multiplied by 17, would give 2¾ lbs. for the amount eliminated from the whole body in 24 hours. It was found, however, that different regions of the body gave-off, in proportion to their surface, very different quantities of fluid: thus, in no instance was the amount discharged by the leg equal to that given-off by the arm. Moreover, the three experimenters furnished very different proportions of sweat under the same circumstances: thus, with active exercise in the sun, the proportion between them was as 1 : 2·3 : 4·4, and in another experiment as 1 : 1·7 : 2·06. Funke draws the conclusion from his experiments, that the entire amount of perspiration from the whole body may fluctuate from about 2 ounces (819 grains) to about 29 ounces (12,588 grains) per hour, the quantity of solid residue varying from 14·25 to 107·57 grains per hour. It is difficult to give an average for the 24 hours when the variations are so great; but it may, perhaps, be estimated at about 2 lbs., the exhalation of aqueous vapour by the lungs being rather less than 1 lb. (§ 293). An interesting series of observations has recently been published by Dr. Victor Weyrich§ upon

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* "Archives Génér. de Méd.," 1853, 5me Sér., tom. ii. pp. 1–12.

† "Archiv für Physiol. Heilkunde," band ii. pp. 73-104.

‡ "Beiträge zur Kenntniss der Schweiss Secretion;" Moleschott's "Untersuchungen zur Naturlehre," u. s. w. iv. p. 36.

§ "Die unmerkliche Wasserwerdunstung der Menschlichen Haut;" Leipzig, 1862. See Abstract in "Med.-Chir. Rev.," 1863, vol. ii. p. 359.

the relative amounts of insensible perspiration under different conditions. The instrument he employed was a modification of Daniell's hygrometer; and his experiments extended over more than a year. He found that variations of temperature between 55° and 70° F. produced little effect; but every 1° C. (= 1⅘° F.) above 70° F. occasioned an increase of 2 per cent in the total amount of vapour exhaled, and for every 1° C. below 55° F. there was a diminution of from 1 to 1½ per cent. He observed that the effects of the relative moisture of the air were in great measure concealed by variations in temperature; so that the highest averages of insensible perspiration occurred, not with the lowest, but with moderate amounts of moisture in the air. The minimum amount of perspiration always occurred on rising in the morning, being then 25 per cent below the average. The maximum amount was eliminated at noon, when it rose to 52 above the minimum. Food invariably increased the cutaneous transpiration, coffee and tea having a particularly powerful influence. The increase occurred soonest after breakfast, but was greatest and most permanent after dinner. Moderate muscular or mental exertion slightly increased the amount of perspiration, but fatigue and exhaustion produced a considerable decrease. Violent muscular effort raised it to 77 per cent above the mean; severe intellectual labour, 42 per cent. During sweating, the rise was equal to 116 per cent over the mean, but after sweating it fell even to 26 per cent below the mean. It varies greatly, according to the conditions of the atmosphere, and that of the body itself, in respect to exposure, food, exercise, and activity of other secretions; and these variations, as we shall hereafter see (§ 408), have a most important share in the regulation of the temperature of the body.—The whole amount of Cutaneous transpiration, 'sensible' and 'insensible,' is greatly increased by heat and dryness of the surrounding air; for the heat occasions the determination of an augmented amount of blood to the cutaneous vessels; and of the fluid which thus transudes, a large portion is carried-off in the state of vapour. The more the heated atmosphere is already charged with watery vapour, the smaller will be the proportion of the transuded fluid that will thus 'insensibly' pass away; and the more will accumulate as 'sensible' perspiration. Exact observations on this point, however, are much wanting, in which not merely the temperature, but the hygrometric state of the air should be precisely determined; the best hitherto recorded being those made by Dr. Southwood Smith* at the Phœnix Gas Works, in which the former element only was carefully noted. These observations were made upon eight of the workmen employed in 'drawing' and 'charging' the retorts and in making-up the fires, during which they are exposed to intense heat; the men were accurately weighed in their clothes, immediately before they began, and after they had finished their work; and in the interval between the first and second weighings, they were not allowed to partake of any solid or liquid *ingesta*, nor to part with urine or fæces.

Experiment I. Nov. 18, 1836. Day bright and clear. Temperature of the air in which the men worked, 60° Fahr. Barometer 29·25 in. to 29·4 in. Duration of labour, 45 minutes.—Average loss of weight, 3 lbs. 6 oz.; maximum, 4 lbs. 3 oz.; minimum, 2 lbs. 8 oz.

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* "Philosophy of Health," vol. ii. pp. 391–396.

Experiment II. Nov. 25, 1836. Day foggy, with scarcely any wind. Temperature of the air, 39° Fahr. Barometer 29·8. Duration of labour, 75 minutes.—Average loss of weight, 2 lbs. 2 oz.; maximum, 2 lbs. 15 oz.; minimum, 14 oz.

Experiment III. June 3, 1837. Day exceedingly bright and clear, with little wind. Temperature of the air, 60°. Duration of labour, 60 minutes.—Average loss of weight, 2 lbs. 8 oz.; maximum, 3 lbs.; minimum, 2 lbs.

Experiment IV. On the same day, two other men worked in an unusually hot place for 70 minutes; the loss of weight of one of these was 4 lbs. 14 oz.; and of the other 5 lbs. 2 oz.

Although the individuals subjected to these experiments were not in all instances the same, yet there was enough of identity among them, to admit of the certain inference, that the amount of fluid lost must be influenced by the state of the individual system, as well as by that of the surrounding medium. Thus in the second experiment, Michael Griffiths lost 2 lbs. 6 oz., and Charles Cahell 2 lbs. 15 oz.; whilst in the third, Michael Griffiths lost 3 lbs., and Charles Cahell only 2 lbs. It is probable that the amount of liquid ingested not long previously, might have a considerable influence on the quantity lost by transpiration under such circumstances.

402. That the Cutaneous excretion is to a certain extent vicarious with the Urinary, in regard to the amount of fluid eliminated, has been generally admitted, and is probably true; but the observations of Weyrich have shown that under similar conditions, avoiding extremes, both excretions rise and fall together, and that, consequently, no deductions can be drawn as to the amount of perspiration given-off from any estimates of the volume of urine discharged. We must not disregard the circumstance, however, that these two excretions are to a certain extent vicarious, in regard to the elimination of the products of the 'waste' of the system. The share which the Skin has in this office has probably been generally underrated. As we have seen (§ 400), there is reason to believe that at least 100 grains of azotized matter are excreted from it daily; and any cause which checks this excretion must throw additional labour on the kidneys, and will be likely to produce disorder of their function.—From the experiments of Scharling and Hannover, it would appear that the proportion of Carbonic acid eliminated by the Skin is to that discharged by the Lungs as 1 : 38.—The secreting action of the Skin is influenced by general conditions of the vascular and nervous systems, which are as yet ill understood. It is quite certain, however, that through the influence of the latter the secretion may be excited or suspended; this is seen on the one hand in the state of syncope, and in the effects of depressing emotions, especially fear, and its more aggravated condition, terror; and on the other, in the dry condition of the skin during states of high nervous excitement. It is very probable that, in many forms of fever, the suppression of the perspiration is a cause, rather than an effect, of disordered vascular action; for there are several morbid conditions of large parts of the surface, in which the suppression of the transpiration appears to be one of the chief sources of danger, having a tendency to produce congestion and inflammation of internal organs. From the experiments of Dr. Fourcault, which have

been confirmed by Valentin,* it appears that complete suppression of the perspiration in animals, by means of a varnish applied over the skin, gives rise to a state termed by him 'cutaneous asphyxia;' which is marked by imperfect arterialization of the blood, and considerable fall of temperature; and which, as it produces death in the lower animals, would probably do the same in Man. A partial suppression by the same means gives rise to febrile symptoms, and to albuminuria.† In Valentin's experiments it was found that removal to a room of high temperature (71° to 104° Fahr.) was followed by remarkable temporary improvement in the condition of the animals, sensibility and voluntary motor power being reacquired, and in some instances food being taken. Death, however, always ultimately occurred.—There can be no doubt whatever, that imperfect action of the Cutaneous glandulæ, consequent upon inactive habits of life and want of ablution, is a very frequent source of disorder of the general system; occasioning the accumulation of that decomposing organic matter in the blood, which it is the special office of these glandulæ to eliminate. Hence the due maintenance of health requires that this excretion should be promoted by the use of the natural and appropriate means just referred-to; and this is the more necessary, when from any cause the function of the kidneys is imperfectly performed. There are many diseased states, moreover, in which there appears to be a special determination of the *materies morbi* to the Skin; and in which, therefore, the use of means that promote the cutaneous excretion constitutes the most efficient method of eliminating it from the blood.‡

CHAPTER X.

EVOLUTION OF HEAT, LIGHT, AND ELECTRICITY.

1. *General Considerations.*

403. The series of Nutritive operations which has now been passed in review, has been shown to consist in the continual appropriation, by the Animal organism, of certain 'organic compounds' or 'alimentary materials,' which have been generated for its use by Plants; and in the constant restoration of their elements to the Inorganic world, either in the

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* "Archiv für Physiolog. Heilk.," band ii. 1858, p. 433.

† See his important Treatise, "Causes Générales des Maladies Chroniques," &c., 1844; and "Brit. and For. Med. Rev.," vol. xx. pp. 106–108.

‡ The practical value of active diaphoresis in many febrile diseases, is well understood by the native practitioners among the Negroes of the Guinea Coast; who, according to Dr. Daniell ("Medical Topography and Native Diseases of the Gulf of Guinea," pp. 119–20), make use of it most successfully in the treatment of adynamic remittent fevers. Dr. Daniell states that having himself had abundant experience of its efficacy, he has no doubt of its superiority in these cases to the ordinary practice of venesection, saline purgatives, large doses of calomel, &c. And he has repeatedly stated that one great secret of preserving health in tropical climates, lies in due attention to the cutaneous functions.

very same forms of combination in which they originally existed there, or as products of incipient decay, by whose further decomposition those simple binary compounds will be reproduced. And thus, so far as the material components of the Organic Creation are concerned, the agency of Vegetable life is concerned in withdrawing them from the Mineral world, and that of Animal life in returning them to it, after they have served their purpose in the living structure. But if we examine into the source of those active powers or 'forces,' on whose operation every change, no less in the organized body, than in what is commonly designated as 'inert' matter, is dependent, we shall find that they are all traceable to the solar radiations. It is by the action of the Light and Heat of the Sun upon the Vegetable germ, that it is enabled to exercise its wonderful transforming capacity, whereby it extracts carbon, hydrogen, nitrogen, and oxygen, from the carbonic acid, water, and ammonia furnished by the atmosphere or the soil; and that it converts these into the albuminous, saccharine, and oleaginous compounds, which are the destined food of Animals. And it is under the influence of Heat chiefly derived from the same source, that the greater number of tribes of Animals are enabled to apply these compounds to the purposes of organization; and that, through the peculiar instruments thus constructed, those various kinds of *Vital Force* are evolved, whose operations are so different from any which we witness in the Inorganic world. Accordingly we observe that the 'rate of life' in this larger proportion of the Animal kingdom, is regulated, as in Plants, by the amount of Heat supplied to the organism from external sources; and that, when the external temperature is reduced below a certain point, there is an entire cessation of all vital activity. But there are certain tribes, especially Birds and Mammals, which possess the power of generating *Heat* within themselves, to such a degree as to render the rate of their vital processes almost entirely independent of external influences; and there is probably no one species that can exercise this power more effectually, and through a greater range of external conditions, than Man is able to do. Of this we shall presently have evidence.—The evolution of *Light*, again, is by no means an unusual phenomenon among the lower tribes of Animals; but where it does occur, it usually appears to have some special purpose, as is obvious enough in the case of the glow-worm and other luminous Insects. But the luminosity which is occasionally exhibited in Man must be regarded as an altogether abnormal phenomenon, whose physiological interest arises out of the peculiarity of the circumstances under which it presents itself. —Of the degree in which *Electricity* is generated in the living body, we know comparatively little. There can be no doubt that a disturbance of Electric polarity takes place in every action of Organic as well as of Inorganic Chemistry; and thus that every molecular change in the Animal as well as in the Vegetable organism must involve an alteration in its electric condition. But it would seem that in the Animal body generally, these alterations are made to balance each other so exactly, that no considerable disturbance of the electric equilibrium ordinarily takes place in the organism as a whole; and it is only in certain peculiar cases (as in the Electric Fishes) that a provision exists for the generation of Electricity in considerable amount and intensity, with a view to some special purpose. In the Human subject, however, an extraordinary production of free Electricity, as of Light, occasionally presents itself; and this, taken in connection with other evidence, would seem rather to indicate a departure from the *balance* usually maintained between the opposite electrical changes continually taking place, than to be due to the introduction of any extraordinary sources of electric disturbance.

2. *Evolution of Heat.*

404. All the vital actions of the body of Man, as of that of 'warm-blooded' animals generally, require an elevated temperature as a condition of their performance; and the high degree of constancy and regularity which is observable in these actions, appears to depend in great degree upon the provision which the organism contains within itself, for the maintenance of that temperature at a fixed standard. This constancy and regularity are most remarkably exhibited in the various *periodical* changes to which the body is subject both in health and in disease; the uniformity of whose recurrence is due to a corresponding uniformity in the rate of vital action taking place in the interval. Thus, as will be shown hereafter, the period of parturition is in great degree determined by the maturation of the fœtal structures; and the uniformity of the time which this requires (like the corresponding uniformity in the period of development in the embryo-bird) may be fairly attributed to the regularity of the supply of Heat, which is the power that especially determines the formative operations. For the periods of all similar phenomena in 'cold-blooded' animals, which have no power of maintaining an independent temperature, exhibit no such uniformity; being entirely dependent (as in Plants) upon the degree of *external* warmth to which their bodies are subjected.—We shall now inquire, in the first place, into the amount of Heat thus generated by Man; and then into the sources of its production.

405. Our present knowledge of the ordinary Temperature of the Human body under different circumstances, is chiefly due to the investigations of Dr. J. Davy.[*]—The first series of his observations included 114 individuals of both sexes, of different ages, and among various races, in different latitudes, and under various temperatures; the external temperature, however, was in no instance very low, and the variations were by no means extreme. The mean of the ages of all the individuals was 27 years. The following is a general statement of the results, the temperature of the body having been ascertained by a thermometer placed under the tongue:—

Temperature of the air . .	60°	Average temperature of the body	98·28°
,, ,,	69°	,, ,, ,,	98·15°
,, ,,	78°	,, ,, ,,	98·85°
,, ,,	79·5°	,, ,, ,,	99·21°
,, ,,	80°	,, ,, ,,	99·67°
,, ,,	82°	,, ,, ,,	99·9°
Mean of all the experiments	74°	Mean of all the experiments .	100°
Highest temperature of air	82°	Highest temperature of body .	102°
Lowest temperature of air	60°	Lowest temperature of body .	96·5°

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[*] See Dr. Davy's successive Memoirs in the "Philosophical Transactions" for 1814 (republished in his "Anatomical and Physiological Researches"), 1844, 1845, and 1850. See also Brown-Séquard ("Journal de la Physiologie," 1859, p. 549), whose experiments

From this we see that the variations noted by Dr. Davy, which were evidently in part the consequence of variations in external temperature, but which were also partly attributable to individual peculiarities, amounted to 5½ degrees; the lower extreme might be found to undergo still further depression, if the inquiries were carried-on in very cold climates.—Dr. Davy's subsequent inquiries have been directed to the determination of the various influences which tend to produce a departure from the average; and it will be advantageous to present his results in a systematized form, in combination with those of other observers. The most important of these variations seem to be those dependent upon Age, Period of the day, Exercise or Repose, Ingestion of Food or Drink, and External Temperature.

I. The temperature of *Infants*, according to the observations of Dr. Davy, M. Roger,* and of Dr. G. C. Holland,† is somewhat higher than that of adults,‡ provided that they are placed in conditions favourable to its sustenance; but, as will be shown hereafter, infants and young children are very inferior to adults in their power of resisting the depressing influence of external cold. Their temperature, when examined immediately after birth by a thermometer in the axilla, is nearly 100°; but it quickly falls to about 95·5°, and gradually rises in the course of the next twenty-four hours to about 97·7° in weakly subjects, and to 99·5° in strong infants. Between four months and six years of age, M. Roger found the average temperature to be 98·9°; and, between six and fourteen years of age, 99·16°.—The temperature of *aged* persons, from the observations of Dr. J. Davy, does not seem to be below that of persons in the vigour of life, provided that there be no external depressing influences; but they seem, like infants and young children, to have less power of resisting external cold, the temperature of their bodies being more easily and considerably reduced by it than is that of adults; and hence probably it has happened, that popular opinion assigns to them an habitually inferior temperature.

II. A slight *diurnal* variation in the temperature of the body appears usually to take place, quite irrespectively of external heat or cold; but this does not seem to be very constant either in its period or its degree, and is seldom very considerable. Thus Dr. Davy found from a long series of observations carried-on upon himself whilst in England, that the body was warmest in the morning, and coldest at night; whilst the reverse was the case in Barbadoes. The following Table gives his average results:—

	Mean Temperature under the Tongue.			*Temperature of Room.*		
England	7 8 A.M. 98·74°	2–4 P.M. 98·52°	12 P.M. 97·92°	7–8 A.M. 50·9°	2–4 P.M. 54·7°	12 P.M. 62°
Barbadoes	6–7 A.M. 98·07°	12–2 P.M. 98·9°	9–11 P.M. 99°	6–7 A.M. 76·7°	12–2 P.M. 83·6°	9–11 P.M. 79°

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essentially corroborate those of Dr. Davy, as well as the older ones of MM. Eydoux and Souleyet ("Comptes Rendus," 1838, p. 457), except that he found a greater difference in the temperature of the men he examined, though the variation of the atmospheric temperature was much less.

* "Archiv. Gén. de Méd.," 1844. † "Inquiry into the Laws of Life," 1829.

‡ Dr. W. F. Edwards ("On the Influence of Physical Agents on Life," p. 115) gives

From the observations of M. Chossat on Birds, in which the diurnal variation amounts to 1½° Fahr., it seems that the maximum pretty constantly occurs at noon, and the minimum near midnight; and this corresponds well with what has already been pointed-out, with regard to the relative activity of respiration at different periods of the twenty-four hours (§ 288, IX.). Probably there is a less capacity for generating heat during the night; so that, if the body be insufficiently protected by clothing, or be exposed to a low degree of external temperature, its own temperature will be more readily lowered: and thus the minimum of the whole day may come to present itself at this part of it, in a temperate climate; whilst in a tropical climate, the light bed-covering and free circulation of air usual in the sleeping-room, together with the reducing influence of repose, would tend to render the early-morning temperature the lowest.

III. That an increase in the heat of the body is produced by *exercise*, and that repose tends to its reduction, is a matter of familiar experience; but the observations of Dr. Davy show that there is scarcely any perceptible difference in the heat of the deep-seated parts, the augmentation and depression being confined to the extremities. Thus, on one occasion recorded by him, the temperature of the air of the room before walking being 60°, that of the feet (shown by a thermometer placed between the toes) being only 66°, that of the thermometer under the tongue being 98°, and that of the urine being 100°,—the temperature after a walk in the open air at 40°, the exercise having diffused a feeling of gentle warmth through the body, was 96·5° in the feet, 97° in the hands, 98° under the tongue, and 101° in the urine. So, on another occasion, the temperature having been 66° in the room, 75° in the feet, 81° in the hands, 98° under the tongue, and 100° in the urine,—after a walk in air at 50° the temperature was 99° in the feet, 98° in the hands, 98° under the tongue, and 101·5° in the urine. These effects are, therefore, in all probability, chiefly due to an increase in the energy and frequency of the heart's contractions, by which means the warm blood is driven with greater velocity through the extreme capillaries, imparting its heat to the surrounding parts.—The experiments of Becquerel, moreover, have shown that a certain amount of heat is developed during the active contraction of muscular tissue, the rise in temperature of a muscle like the Biceps, after a few powerful contractions, being as much as 1° Fahr.; and he regarded this increase in temperature as due to the increased energy of the chemical changes, and in some measure also to the mechanical effects of friction, &c., taking place in the contracting muscle. M. J. Béclard,* however, considers the amount of heat produced to be in inverse relation to the mechanical effect obtained; for he found that more heat is developed when the muscle is unable to shorten itself during contraction, as in the case of a man striving to overcome an insuperable obstacle, than when the muscle fully contracts, as in lifting light weights. Thus it would seem that the Force which manifests itself in sensible Motion in one case, manifests itself as Heat (a different mode of motion) in the other.

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as the result of his observations, which were only ten in number, that the temperature of infants is lower than that stated above; but it is obvious that these observations were made during the period of depression which occurs in the first few days, whilst the respiratory function is becoming established.

[*] "Comptes Rendus," 1860, vol. i. p. 471.

IV. The influence of *ingestion of food* upon the temperature of the body has not yet been duly investigated. Common experience leads to the conclusion, that after a meal, as after exercise, there is a greater warmth in the extremities; but Dr. Davy's observations show that, in his own person, whilst in England, there was usually an appreciable depression immediately after dinner, though in Barbadoes the effect of a moderate meal was to produce an elevation. In both cases, however, Dr. D. observed that the ingestion of *wine* has a positively-depressing influence on the temperature of the body, which increases with the quantity taken; and it may have been the constant employment of wine with his dinner, which was the real cause of the depression observed in England.*

V. The influence of *external temperature* is sufficiently apparent in the observations already cited; for although external cold may act in a different degree on different individuals, according to their respective ages, powers of resistance, &c., yet there is ample proof that on the whole a continued exposure to it reduces the temperature of the body somewhat below its ordinary standard, whilst continued exposure to heat occasions a slight elevation in the temperature of the body. The influence of cold is, of course, most powerfully exerted when the body is at rest; and under such circumstances Dr. Davy found the temperature of his own body to be reduced, on an average of four observations, to 96·7°, the average temperature of the surrounding air having been 37°. On comparing the bodily temperature of different individuals working in rooms of various temperatures in the same factory, Dr. Davy found the tongue-thermometer rise to 100° in one man, and to 100·5° in another who had been working for some hours in a room at 92°; whilst it was 99° in a young woman who worked in a room at 73°, and only 97·5° in another who worked in a temperature of 60°.—The effects of seasonal change are less marked in Man, than they are in the lower animals, which are more exposed to extremes of temperature; but it seems principally exerted in modifying the heat-producing power. For it has been shown by Dr. W. F. Edwards,† that warm-blooded animals are more speedily killed by extreme cold in summer than in winter; and it seems probable, therefore, that we are partly to attribute the peculiar chilling influence of a cold day in summer, and the oppressiveness of a warm day in winter, to the seasonal change in the body itself; although the effect is doubtless referable in part to the effect of contrast upon our own feelings.

406. The usual Temperature of the body occasionally undergoes considerable alteration in *disease;* and this in the way either of increase or of diminution. Thus in maladies which involve an acceleration of pulse

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* This difference in effect noted by Dr. Davy, between the effects of a moderate quantity of wine taken with dinner in England and in Barbadoes, seems explicable on the supposition that the presence of wine in the blood may sometimes diminish for a time the energy of the proper combustive process. When the temperature of the atmosphere is considerably below that of the body, this retardation of the combustive process occasioned by the wine will allow the heat of the body to be lowered by it, notwithstanding the tendency to increased activity of the circulation and respiration which the meal alone would exert. In a warm climate, on the other hand, the cooling influence of the external air would not be sufficient to produce this reduction in the temperature of the body, notwithstanding the retarding influence of the wine upon the combustive process.

† Op. cit.

and a quickening of the respiration, the temperature is generally higher than usual, even though a large portion of the lung may be unfit for its function. This is often remarkably seen in the last stages of phthisis, when the inspirations are extremely rapid, and the pulse so quick as scarcely to admit of being counted; the skin, in such cases, often becomes almost painfully hot. On the other hand, in diseases of the contrary character, such as 'morbus cœruleus,' asthma, and cholera, the temperature of the body falls; a reduction to 78° having been noticed in the former maladies, and to 67° in the latter. The range observed by M. Andral in diseases which less affected the calorifying function, was from 95° to 107·6°; and by M. Roger (loc. cit.), in diseases of children, from 74·3 to 108·5. Prof. Dunglison[*] speaks of having seen the thermometer at 106° in scarlatina and typhus; and Dr. Francis Home[†] found it to stand at 104° in two individuals in the cold stage of an intermittent, whilst it afterwards fell to 101°, and subsequently to 99°, during the sweating stage. Dr. Edwards mentions a case of tetanus, in which the temperature of the body rose to 110$\frac{3}{4}$°. The following observations have been made on this subject by M. Donné:[‡] in a case of puerperal fever, the pulse being 168, and the respirations 48 per minute, the temperature was 104°; in a case of hypertrophy of the heart, the pulse being 150, and the respirations 34, the temperature was 103°; in a case of typhoid fever, the pulse being 136, and the respirations 50, the temperature was 104°; and in a case of phthisis, the pulse being 140, and the respirations 62, the temperature was 102°; on the other hand, in a case of jaundice, in which the pulse was but 52, the temperature was only 96·40°; but the same temperature was observed in a case of diabetes, in which the pulse was 84. These limited observations, whilst they clearly indicate that a *general* relation exists between the temperature of the body and the rapidity of the pulse, also show that this relation is by no means invariable, but that it is liable to be affected by several causes, of which our knowledge is as yet very slight.—It is not a little remarkable that the temperature of the body should sometimes *rise* considerably *after death;* and this not merely in such cases as Cholera, in which it has undergone an extreme depression during the latter part of life; but even in the case of febrile disorders, in which the temperature during life has been above the usual standard. This has been ascertained by Dr. Bennet Dowler,[§] of New Orleans, on the bodies of those yellow-fever subjects which have already been referred-to as exhibiting a remarkable degree of *molecular* life after *somatic* death (§ 242). In one case, for example, the highest temperature during life was in the axilla, 104°; ten minutes after death, it had risen to 109° in the axilla; fifteen minutes afterwards, it was 113° in an incision in the thigh; in twenty minutes, the liver gave 112°; in one hour and forty minutes, the heart gave 109°, and the thigh in the former incision 109°; and in three hours after the removal of all the viscera, a new incision in the thigh gave 110°. It is curious that the maximum heat observed after death should have been in the thigh, and the minimum in the brain; as is shown in the following Table of the highest amount of temperature noted in eight different regions in five subjects:—

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[*] "Human Physiology," 7th edit., vol. ii. p. 225.

[†] "Medical Facts and Experiments," London, 1759.

[‡] "Archiv. Gén. de Méd.," Oct. 1835; and "Brit. and For. Med. Rev.," vol. ii. p. 248.

[§] "Western Journal of Medicine and Surgery," June and Oct., 1844; cited in "Philadelphia Medical Examiner," June, 1845, and in Prof. Dunglison's "Human Physiology," 7th edit., vol. ii. p. 718.

	Thigh.	*Epigastrium.*	*Axilla.*	*Chest.*	*Heart.*	*Brain.*	*Rectum.*	*Liver.*
	113°	111°	109°	107°	109°	102°	111°	112°
	109°	110°	109°	106·5°	106°	101°	109°	109°
	109°	109°	108°	106°	105°	101°	107°	108°
	109°	109°	108°	106°	104°	100°	107°	107°
	108°	109°	107°	105°	104°	99°	106°	106°
Mean	109·6°	109·6°	108·2°	106·1°	105·6°	100·6°	108°	108·4°

407. Although there appears to be, for all kinds of animals, a distinct limit to the variations of bodily temperature, under which their vital operations can be carried on, this limitation does not prevent certain species from existing in the midst of great diversities of external conditions; since they have within themselves the power of compensating for these, in a very extraordinary degree. This power seems to exist in Man to a higher amount than in most other animals; since he can not only support, but enjoy life, under extremes of which either would be fatal to many. In many parts of the tropical zone, the thermometer rises every day, through a large portion of the year, to 110°; and in British India it is said to be seen occasionally at 130°. On the other hand, the degree of cold frequently sustained by Arctic voyagers, and quite endurable under proper precautions, appears much more astonishing; by Captain Parry the thermometer has been seen as low as —55°, or 87° below the freezing point; by Captain Franklin at —58°, or 90° below the freezing point; and by Captain Back at —70°, or 102° below the freezing point. In both cases, the effect of the atmospheric temperature on the body is greatly influenced by the condition of the air as to motion or rest: thus, every one has heard of the almost unbearable oppressiveness of the 'sirocco' or hot wind of Sicily and Italy, the actual temperature of which is not higher than has often been experienced without any great discomfort when the air is calm; and, on the other side, it may be mentioned that, in the experience of many Arctic voyagers, a temperature of —50° may be sustained, when the air is perfectly still, with less inconvenience than is caused by air in motion at a temperature fifty degrees higher.* This is quite conformable to what might be anticipated on physical principles.

408. Again, the degree of *moisture* contained in a heated atmosphere, makes a great difference in the degree of elevation of temperature which may be sustained without inconvenience. Many instances are on record,

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* The Author has been informed by Sir John Richardson, that in his last Arctic Expedition, whilst at winter-quarters, he was accustomed to go from his sitting-room to the magnetic observatory at a short distance (about an ordinary street's breadth), without feeling it necessary even to put on a great-coat; although the temperature of the former was about 50°, and that of the air through which he had to pass to the latter was —50°, the difference being 100°. This immunity from chilling influence was chiefly attributable to the *dryness* and *stillness* of the atmosphere; but it is worthy of note that Sir J. R. and the whole of his party on this expedition, abstained entirely from alcoholic liquors; and the Author has received his personal assurance, that his experience on this occasion fully bore-out his previous conviction, that continued severe cold is *much better* borne without recourse to these stimulants, than under the employment of them.

of a heat of from 250° to 280° being endured in *dry* air for a considerable length of time, even by persons unaccustomed to a particularly high temperature; and persons whose occupations are such as to require it, can sustain a much higher degree of heat, though not perhaps for any long period. The workmen of the late Sir F. Chantrey were accustomed to enter a furnace in which his moulds were dried, whilst the floor was red-hot, and a thermometer in the air stood at 350°; and Chabert the "Fire-king" was in the habit of entering an oven whose temperature was from 400° to 600°.* It is possible that these feats might be easily matched by many workmen who are habitually exposed to high temperatures; such as those employed in Iron-foundries, Glass-houses, and Gas-works. In all these instances, the dryness of the air facilitates the rapid vaporization of the fluid, whose secretion by the Cutaneous glandulæ is promoted by heat applied to the surface; and the large amount of caloric which is consumed in this change, is for the most part withdrawn from the body, the temperature of which is thus kept-down.

409. Exposure to a very elevated temperature, however, if continued for a sufficient length of time, does produce a certain elevation of that of the body; as might be expected from the statements already made, in regard to the variation in the heat of the body with changes in atmospheric temperature (§ 405). In the experiments of MM. Berger and Delaroche,† it was found that, after the body had been exposed to air of 120° during 17 minutes, a thermometer placed in the mouth rose nearly 7° above the ordinary temperature; it may be remarked, however, that as the body was immersed in a close box, from which the head projected (in order to avoid the direct influence of the heated air on the temperature of the mouth), the air had probably become charged with the vapour exhaled from the surface, and had therefore somewhat of the effects of a moist atmosphere. At any rate, the temperature of the body does not appear to rise, under any circumstances, to a degree very much greater than this. In one of the experiments of Drs. Fordyce and Blagden,‡ the temperature of a Dog, that had been shut up for half-an-hour in a chamber of which the temperature was between 220° and 236°, was found to have risen from 101° to about 108°. MM. Delaroche and Berger tried several experiments on different species of animals, in order to ascertain the highest temperature to which the body could be raised without the destruction of life, by inclosing them in air heated from 122° to 201°, until they died: the result was very uniform, the temperature of the body at the end of the experiment only varying in the different species between 11° and 13° above their natural standard: whence it

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* The wonderful feats performed by many individuals from time to time—of dipping the hand into melted lead, laying hold of a red-hot iron, &c.—have been recently shown by M. de Boutigny to be explicable upon very simple principles. For in all such cases a thin film of aqueous fluid in the 'spherical state' intervenes between the skin and the heated surface; and a hand which is naturally damp, or which has been slightly moistened, may be safely passed into the stream of *molten iron* as it flows from the furnace; as was demonstrated by M. de Boutigny at the meeting of the British Association at Ipswich in 1851.

† "Expériences sur les Effets qu'une forte Chaleur produit sur l'Economie;" Paris, 1806: and "Journal de Physique," tomes lxiii., lxxi., et lxxvii.

‡ "Philosophical Transactions," 1775.

may be inferred, that an elevation to this degree must be fatal.[*] This elevation would be attained comparatively soon in a *moist* atmosphere; partly because of the greater conducting power of the medium, but principally on account of the check which is put upon the vaporization of the fluid secreted by the skin. Even here, however, custom and acquired constitution have a very striking influence; for whilst the inhabitants of this country are unable to sustain, during more than 10 or 12 minutes, immersion in a vapour-bath of the temperature of 110° or 120°, the Finnish peasantry remain for half an hour or more in a vapour-bath whose temperature finally rises even to 158° or 167°.—Accurate experiments are yet wanting, to determine the influence of humidity on the effects of *cold* air. From experiments on young Birds incapable of maintaining their own temperature, of which some were placed in cold dry air, and others in cold air charged with moisture, it was found by Dr. Edwards that the loss of heat was in both instances the same; the effect of the evaporation from the surface in the former case, being counterbalanced in the latter by the depressing influence of the cold moisture. This influence, the existence of which is a matter of ordinary experience, is probably exerted directly upon the Nervous system.

410. Having thus considered the general facts which indicate the faculty possessed by the living system, in Man and the higher Animals, of keeping-up its temperature to an elevated standard, and of preventing it from being raised much beyond it by any degree of external heat, we have next to inquire to what this faculty is due.[†]—It may be stated as a general fact, that every change in the condition of the organic components of the body, in which their elements enter into new combinations with Oxygen, *must* be a source of the development of Heat. And as we have seen that a considerable part of the carbonic acid and water which are exhaled in Respiration, is formed within the body by the metamorphosis of its own tissues, and that this metamorphosis is promoted by the active exercise of the nervo-muscular apparatus, it follows that in animals whose habits of life are peculiarly active, whilst the temperature of the surrounding medium is sufficiently high to prevent its exerting any considerable cooling influence over them, the combustive process thus maintained may be adequate for the maintenance of the temperature of the body at its normal standard. This seems to be the case with the great Carnivorous quadrupeds of warm climates, and with certain races of Men who lead a life of incessant activity like theirs. But whenever the cooling influence of the atmosphere is greater, or the retrograde metamorphosis of tissue takes place with less activity, some further supply of heat-producing material is required; and this is derived

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[*] Bernard ("Comptes Rendus de la Société de Biologie," 1859, p. 51) attributes the death of the animals in these and similar experiments to a condition analogous to rigor mortis of the heart being established. He found the auricles filled with blood, but the ventricles firmly contracted and empty.

[†] It was affirmed by Dr. Granville ("Phil. Trans.," 1825) that the temperature of the uterus during parturition sometimes rises as high as 120°. In some observations made at the Philadelphia Hospital, however, at the desire of Prof. Dunglison, the temperature of the uterus was not found to be much above that of the vagina; the former being, in three cases, 100°, 102°, and 106°, whilst the latter was 100°, 100°, and 105°. (Prof. Dunglison's "Human Physiology," 7th edit., vol. ii. p. 226.)

either directly from the food, or from a store previously laid-up in the body. Although the albuminous and gelatinous components of the food may be made, by decomposition within the body, to yield saccharine and oleaginous compounds which serve as an immediate *pabulum* to the combustive process (§ 377 *et seq.*), yet this metamorphosis involves a great waste of valuable nutritive material; and the needed supply is much more advantageously derived at once from those farinaceous or oleaginous substances, which are furnished in abundance by the Vegetable kingdom, the latter also by the Animal. No reasonable doubt can any longer be entertained, that the production of Heat by the combustive process is the purpose to which the larger proportion of these substances is destined to be subservient in the bodies of Herbivorous animals and of Man; and the results of experience in regard to their relative heat-producing powers, are in precise accordance with the indications afforded by their chemical composition.

411. Our knowledge of the dependence of all the vital processes in warm-blooded animals upon the Heat of their bodies, and of the dependence of their calorifying power upon the due supply of material for the combustive process, has received some remarkable additions from the experiments of M. Chossat upon Starvation.* He found that Birds, when totally deprived of food and drink, suffered a progressive, though slight, daily diminution of temperature. This diminution was not so much shown by a fall of their maximum heat, as by an increase in the diurnal variation, which he ascertained to occur even in the normal state (§ 405, II.). The average variation in the *inanitiated* state, was about 6° (instead of 1½°), gradually increasing as the animal became weaker; moreover, the gradual rise of temperature, which should have taken place between midnight and noon, was retarded; whilst the fall subsequently to noon commenced much earlier than in the healthy state; so that the *average* of the whole day was lowered by about 4½°, between the *first* and the *penultimate* days of this condition. On the *last* day, the production of heat diminished very rapidly, and the thermometer fell from hour to hour until death supervened; the whole loss on that day being about 25° Fahr., making the *total* depression about 29½°. This depression appears, from the considerations to be presently stated, to be the *immediate* cause of Death.—On examining the amount of loss sustained by the different organs of the body, it was found that 93 per cent of the *Fat* had disappeared; being all, in fact, which *could* be removed; whilst the nervous centres scarcely exhibited any diminution in weight (§ 58). From the constant coincidence between the entire consumption of the fat, and the depression of temperature,—joined to the fact that the duration of life under the inanitiating process evidently varied (other things being equal) with the amount of fat previously accumulated in the body,—the inference seems irresistible, that the calorifying process depended chiefly, if not entirely, on the materials supplied by this substance. Whenever, therefore, the store of combustible matter in the system was exhausted, the inanitiated animals died, by the cooling of their bodies consequent upon the loss of calorifying power.

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* "Recherches Expérimentales sur l'Inanition," Paris, 1843; an analysis of this work will be found in the "Brit. and For. Med. Rev.," April, 1844.

412. That this is the real explanation of the fact, was shown by the results of a series of very remarkable experiments performed by M. Chossat, with the purpose of testing the correctness of this view. When inanitiated animals whose death seemed impending (death having actually taken place in several instances, whilst the preliminary processes of weighing, the application of the thermometer, &c., were being performed,) were subjected to artificial heat, they were almost uniformly restored from a state of insensibility and want of muscular power to a condition of comparative activity; their temperature rose, their muscular power returned, they flew about the room, and took food when it was presented to them; and if the artificial assistance was sufficiently prolonged, and they were not again subjected to the starving process, most of them recovered. If they were left to themselves too early, however, the digestive process was not performed, and they ultimately died. Up to the time when they began to take food, their weight continued to diminish; the secretions being renewed, under the influence of artificial heat, sometimes to a considerable amount. It was not until digestion had actually taken place (which, owing to the weakened functional power, was commonly many hours subsequently to the ingestion of the food), that the animal regained any power of generating heat; so that, if the external source of heat was withdrawn, the body at once cooled: and it was not until the quantity of food actually *digested* was sufficient to support the wants of the body, that its independent power of calorification returned. It is to be remembered that, in such cases, the resources of the body are on the point of being completely exhausted, when the attempt at re-animation is made; consequently it has nothing whatever to fall back upon; and the leaving it to itself *at any time* until fresh resources have been provided for it, is consequently as certain a cause of death, as it would have been in the first instance.

413. It can scarcely be questioned, from the similarity of the phenomena, that Inanition, with its consequent depression of temperature, is the immediate cause of death in various Diseases of Exhaustion: and it seems probable that there are many cases in which the depressing cause is of a temporary nature, and in which a judicious and timely application of artificial heat might prolong life until it has passed-off, just as artificial respiration is serviceable in cases of narcotic poisoning (§ 203). It is especially, perhaps, in those forms of Fever, in which no decided lesion can be discovered after death, that this view has the strongest claim to reception; and the beneficial result of the administration of Alcohol in such conditions, and the large amount in which it may be given with impunity, may probably be accounted-for on this principle. That it acts as a specific stimulus to the Nervous system, cannot be doubted from its effects on the healthy body; but that it serves as a *fuel* to keep-up the calorifying process, appears equally certain.* Its great efficacy in such cases seems to depend upon the readiness with which it will be taken into the circulation, by a simple act of endosmotic imbibition, when the special Absorbent process, dependent upon the peculiar powers of

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* See the articles written by M. Baudot in "L'Union Médicale" for Nov. 1863, in which he has criticized the statements of Perrin, Lallemande, and Duroy, already quoted in this work (§ 52), and shown that, comparatively, but a very small proportion of the alcohol ingested can be recovered in the various excreta.

the cells of the villi (§ 107), is in abeyance. There is no other combustible fluid, whose miscibility and whose density, relatively to that of the Blood, will permit of its rapid absorption by the simple physical process adverted-to.*

414. That the oxidation of certain components of the food or of the tissues is the fundamental source of Animal Heat, is further indicated by the close conformity which we everywhere find, between the activity of the Respiratory process and the amount of Heat which is generated; and this not merely when we compare different tribes of animals with each other, but also when we compare the amount of oxygen absorbed and of carbonic acid exhaled by the same individuals under different degrees of external temperature (§ 288, I.). For we find that the system possesses within itself a regulating power, by which the combustive process is augmented in activity when the cooling influence of the surrounding medium is considerable, so that this influence is resisted; whilst the internal fire (so to speak) is slackened, whenever the temperature of the outer air rises so much as to render the same generation of heat no longer requisite. The appetite for food, and especially for those particular forms of it which best afford the combustive pabulum, varies in the same degree; and thus, when supplied with appropriate nutriment, Man is able to brave the severest cold, without suffering any considerable depression in his bodily temperature.—It would seem that the Cutaneous Respiration (§ 289), small as its amount is, promotes those molecular changes on which the maintenance of Animal Heat depends; for it was found by MM. Becquerel and Breschet,† that when the hair of Rabbits was shaved-off, and a composition of glue, suet, and resin (forming a coating impermeable to the air) was applied to the whole surface, the temperature rapidly fell, notwithstanding the obstacle thus offered to the evaporation of the sweat, whereby, it might be supposed, the temperature of the body would be considerably elevated. In the first rabbit, which had a temperature of 100° before being shaved and plastered, it had fallen to 89½° by the time the material spread over him was dry. An hour afterwards, the thermometer placed in the same parts (the muscles of the thigh and chest) had descended to 76°. In another rabbit, prepared with more care, by the time that the plaster was dry, the temperature of the body was not more than 5½° above that of the surrounding medium, which was at that time 69½°; and in an hour after this, the animal died.—These experiments place in a very striking point of view the importance of the cutaneous surface as a respiratory organ, even in the higher animals; and they enable us to understand how, when the aerating power of the Lungs is nearly destroyed by disease, the heat of the body is kept-up to its natural standard by the action of the skin. A valuable therapeutic indication, also, is derivable from the knowledge which we thus gain, of the importance of the cutaneous respiration; for it leads us to perceive the desirableness of keeping the skin moist, in those febrile diseases in which there is great heat and dryness of the surface, since

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* The Author has stated the very striking results of observations which he has had the opportunity of making upon this point, in his Essay on "The Physiology of Temperance and Total Abstinence," § 218.

† "Comptes Rendus," Oct. 1841. These experiments have been repeated and confirmed by Magendie ("Gazette Médicale," Dec. 6, 1843).

aeration cannot properly take place through a dry membrane. Of the relief afforded by cold or tepid sponging in such cases, experience has given ample evidence.

415. It has been held that the Chemical theory of Calorification is insufficient to account for the total amount of Heat generated by a warm-blooded animal in a given time; this assertion being founded upon the experimental results obtained by M. Dulong. MM. Favre and Silbermann[*] have shown, however, that the original estimates require correction for the true calorific equivalents of carbon and hydrogen; and that this correction having been made, the heat produced by the combustion of the Carbon which is contained in the carbonic acid expired, and by the combustion of such a proportion of the Hydrogen contained in the exhaled water as may be fairly considered to have undergone oxygenation within the system (§ 293), proves to be adequate to compensate for that which would be dissipated by the evaporation of all the water transpired from the skin and lungs, and also to maintain the temperature of the body itself in an atmosphere of ordinary coolness. And to the combustion-heat of carbon and hydrogen, we should also add that of those relatively-minute quantities of Phosphorus and Sulphur, which also undergo oxidation within the system (§ 393), whereby a small additional amount of heat must be generated.—Through whatever diversity of combinations or successive stages of oxidation these elements respectively pass, in their progress to complete or final oxidation, it may be regarded as an indisputable fact, that *they give-out precisely the same amount of heat in the whole, as if they had undergone the most rapid combustion in pure oxygen;* and thus we may look to almost every molecular change in the body, although pre-eminently to those which are concerned in the *disintegration* of its textures and in the elimination of their products by Respiration, as participating in the function of Calorification.—We may estimate the absolute amount of animal heat generated by a man weighing 180 lbs. at about 2,500,000 calories per diem,[†] on the following data. According to Scharling, a man of that weight should eliminate 3700 grains of carbon by the lungs, the combination of which with oxygen to form carbonic acid would yield 1,935,160 calories. Further, if, following Valentin, we admit that the excess of oxygen inspired over that reappearing in the carbonic acid eliminated is applied to the formation of water, there will be a combustion of 210 grains of hydrogen, producing 468,683 calories,

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[*] See their Memoir 'Des Chaleurs de Combustion,' in "Comptes Rendus," tom. xx., xxii.

[†] The terms 'Calory' and 'Unit of Heat' are now generally employed to designate the quantity of Heat requisite to raise 1 gramme (15·44 grains) 1° centigrade (1⅘° Fahr.); 10 calories will therefore raise 1 gramme 10° centigrade, or 5 grammes 2° centigrade. A Unit of Heat may also be expressed mechanically, and Joule has found that the quantity of Heat capable of raising the temperature of 1 lb. of water (between 55° and 60° Fahr.) by 1° Fahr. requires for its evolution the expenditure of a mechanical force equal to the raising of 772 lbs. one foot (Joule, "Phil. Trans.," 1850). Expressed in terms of the French metrical system, the Heat capable of raising 1 gramme of water 1° centigrade is equivalent to a force which would lift to the height of 1 metre 423·55 grammes (Joule), 430 grammes (Ludwig), 424 grammes (Person), 421 grammes (Clausius), and 433 grammes (Tresca and Laboulaye). (See "Eng. Cyclop.," vol. iv., Arts and Sciences Div., p. 640.) According to Favre and Silbermann, 1 gramme of hydrogen, in combining with oxygen, generates 34,462 calories, or will raise that number of grammes of water 1° centigrade; and 1 gramme of carbon, in uniting with oxygen, sets free 8080 calories.

the two together amounting to 2,403,843 calories. Finally, if we consider that these numbers represent the greater part of all the heat generated in the body, we obtain in round numbers 2,500,000 calories, as the amount daily developed, a number which closely approximates to that obtained by Liebig and other chemists from calculations made on the calorific value of the food. Thus, supposing the daily food to be—

			Carbon.	Hydrogen.
Albumen	120 grammes	these contain	64·18	8·60
Fat	90 ,,		70·20	10·26
Starch	330 ,,		146·82	—
Total in grammes			281·20	18 86
Deduct Urinary and Fæcal constituents			29·8	6·3
The remainder to be oxidized		=	251·4	12·56
Now the Carbon would yield	251·4 × 8,080	=	2,031,312	Calories.
And the Hydrogen	12·56 × 34,462	=	432,842	,,
Total			2,464,154	Calories.

This amount of heat would be sufficient, if converted into mechanical force, to raise 1,166,000 kilogrammes (= 11,451½ tons) one metre high. Béclard[*] estimates that a man daily developes sufficient heat to raise 55 lbs. of water from 32° to 212° F.

416. It cannot be denied, however, that there are certain phenomena which seem at first sight to be completely opposed to the chemical theory of calorification, and which can scarcely be explained in accordance with it, save by a considerable modification in our usual ideas. The class ot facts to which reference is here made, are those which indicate that the Nervous System has a very important concern in the process, and that it is, in fact, one of the immediate instruments in the development of heat. Thus it was experimentally shown by Sir B. Brodie,[†] that when the Brain is cut-off from the spinal cord, or its functions are suspended by the agency of a narcotic, and artificial respiration is practised so that the circulation is maintained, the body not only loses heat rapidly, but may even cool *more rapidly* than the body of an animal similarly treated, but in which artificial respiration is not performed. Now it is certainly true, as was subsequently pointed-out by Drs. Wilson Philip and Hastings,[‡] and by Dr. C. Williams,[§] that the effect of the artificial performance of respiration depends in some degree upon the mode in which it is accomplished; for that if, as in most of Sir B. Brodie's experiments, the in sufflation be repeated 30 times or more in a minute, the cooling effect of the air thus introduced is greater than the warming effect of the imperfect respiratory change to which it becomes subservient; whilst if the insufflation be repeated only twelve times in a minute, the cooling of the body, as compared with that of a body in which the circulation is not thus maintained, is retarded, instead of being accelerated. But still it is evident from Sir B. Brodie's experiments, that the withdrawal of the influence of the Encephalon has a positively-depressing effect upon the Calorific function; for the rapid fall of temperature took place even in

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[*] "Physiol.," 1862, p. 561.

[†] "Philosophical Transactions," 1811, 1812; and "Physiological Researches."

[‡] See Dr. Wilson Philip's "Experimental Inquiry into the Laws of the Vital Functions," 3rd edit. p. 180.

[§] "Edinb. Med.-Chir. Trans.," vol. ii. p. 192.

cases, in which the amount of carbonic acid exhaled during the performance of artificial respiration was fully equal to the normal quantity; and the subsequent experiments of MM. Le Gallois* and Chossat† are decidedly confirmatory of this conclusion, whilst they extend it to other lesions of the Nervous centres, the influence of which upon the calorific function appears to be proportional to their severity.—Various pathological phenomena, moreover, indicate that the withdrawal of nervous influence from any part of the body usually tends to produce a depression of its temperature, and this especially in the extremities; thus Mr. H. Earle‡ found the temperature of paralysed limbs slightly lower than that of sound limbs; so Prof. Dunglison has noticed that in one case of hemiplegia of five months' standing, the temperature of the axilla was 96½° on the sound side, and 96° on the paralysed; whilst that of the hand was 87° on the sound side, and only 79½° on the paralysed; and in another case of only a fortnight's duration, the temperature of the axilla was 100° on the sound side, and only 98¼° on the paralysed, whilst that of the hand was 94° on the sound side, and 90° on the paralysed.§

417. It is a remarkable fact, however, that the disturbance of temperature produced by severe injuries of the Nervous system, occasionally shows itself in the opposite direction. Thus it has been noticed by many experimenters, that one of the first effects of division of the spinal cord in the back, in warm-blooded animals, is to *raise* the temperature of the posterior part of the body, this elevation continuing for some hours. A case is recorded by Sir B. Brodie, in which, the spinal cord having been so seriously injured in the lower part of the cervical region that the whole of the nerves passing-off below were completely paralysed, the heat of the body, as shown by a thermometer placed on the inside of the groin, was not less than 111°; and this notwithstanding that the respiratory function was very imperfectly performed, the number of inspirations being considerably reduced, and the countenance being livid.‖ And Prof. Dunglison states that, notwithstanding the usual depression of the thermometer on the hemiplegic side, it is not unfrequently found to be more elevated than on the sound side.¶ According to the experiments of M. Cl. Bernard** it appears that an elevation of temperature constantly takes place on one side of the face, when the trunk which unites the Sympathetic ganglia of the neck on that side is cut through; this increase being not only perceptible to the touch, but showing itself by a thermometer introduced into the nostrils or ears, even to the extent of from 7° to 11° Fahr. When the superior cervical ganglion is removed, the same effect is produced, and with yet greater intensity. This difference is maintained for many months, and is not apparently connected with the occurrence of inflammation, congestion, œdêma, or any other pathological change in the tissues, though the sensibility of the parts thus affected is no less augmented than their temperature; moreover, it is not prevented from manifesting itself by the division of any of the cerebro-spinal nerves of the face. The fact, however, appears to be sufficiently explained by

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* "Annales de Chimie," 1817; and "Œuvres de M. Le Gallois," tom. ii.

† "Mémoire sur l'Influence de Système Nerveux sur la Chaleur Animale."

‡ "Medico-Chirurgical Transactions," vol. vii.

§ "Human Physiology," 7th edit., vol. ii. p. 238.

‖ "Medical Gazette," June, 1836; and "Physiological Researches," p. 121.

¶ "Amer. Med. Intelligencer," Oct. 15, 1838.

** "Gazette Médicale," Févr. 21, 1852.

the relaxation of the walls of the smaller arteries (producing a state resembling a permanent 'blush'), and the consequent increase in the afflux of blood to the part, which has been shown by Dr. Aug. Waller to result from this operation. (See § 227.) A curious experiment made by Bernard tends to show that the quantity of blood taken up by any one organ is supplied to it at the expense of another; and that the excess of heat developed at one point of the body is compensated for by a diminution in some other part. He found that on making a section of the Sympathetic in the neck of a Rabbit, both of whose ears had previously a temperature of 95° F., the temperature rose to 100° F. on the side on which the section was made, whilst it fell to 91° F. on the opposite side. When, however, the peripheral end of the cut nerve was galvanized, the temperature fell in the corresponding ear, and rose in the opposite one.*

418. The influence which conditions of the Nervous System are thus shown to possess over the function of Calorification, has led some Physiologists and even Chemists to the conclusion, that the production of Heat is essentially dependent upon Nervous agency, of which it is one of the manifestations. But, as Prof. Liebig justly observes, "if this view exclude chemical action, or changes in the arrangement of the elementary particles, as a condition of nervous agency, it means nothing else than to derive the presence of motion, the manifestation of force, from nothing. But no force, no power, can come of nothing."† That the production of heat in living bodies may take place without any possible assistance from Nervous agency, is manifest from the phenomena of Vegetable heat; and there can be no reasonable doubt that the source of this production is a true combustive process. And the evidence afforded by the post-mortem production of heat in the Human subject (§ 406) conclusively points to the same result; more particularly as the elevation of temperature observed in the brain was uniformly *less* than that which was manifested in other large organs.—But the phenomena just enumerated (and many others that might be cited) can scarcely be accounted-for, without admitting that the Nervous system exerts an important modifying power upon the temperature of the body, which may be either elevated or depressed through its agency; and the question now arises, whether this operation takes place through the influence which the Nervous system exerts over the molecular processes of Nutrition, Secretion, &c., or through some more direct method. It can scarcely be denied that the first of these channels affords not merely a possible, but also a probable means, for the exercise of such influence; but still it is difficult to conceive that any great effect can be thus produced, since, as already shown, it is not so much in the growth as in the disintegration of textures, that heat is produced by the oxidation of their components. On the other hand, from the close relation which exists between the Vital and the Physical forces, it can scarcely be regarded as improbable that the Nervous force, generated by molecular changes in the Nervous substance, may manifest itself under the form of Heat, just as we know that it manifests itself (in the electric Fishes, &c.) under that of Electricity.‡ And thus it is quite conceivable, that one mode in which alimentary

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* Bernard, "Leçons," 1859, 6ème Leçon.

† "Animal Chemistry," 3rd edit. p. 39.

‡ See "Princ. of Comp. Phys.," §§ 461–466.

materials may be applied to the maintenance of Animal Heat, may consist in their subservience to these molecular changes, which seem to take place in the Nervous substance with more activity than in any other tissue; and thus a large measure of caloric may be generated through the immediate instrumentality of the Nervous system, notwithstanding that the ultimate source of its development lies (as in the Chemical theory) in the oxidation of the elements of the food.—Such an hypothesis will be found consistent, the Author believes, with all the well-ascertained facts of the case; for whilst it assigns their full value to all those proofs, which establish (in his mind) the necessary dependence of Calorification upon the changes to which the Respiration is subservient, and thus upon the supply of combustive material on the one hand and of oxygen on the other, it also assigns a definite *modus operandi* to the Nervous system, as an instrument largely concerned in the production and distribution of the heat thus generated,—this *modus operandi*, moreover, being in such complete harmony with the other manifestations of Nervous power, that its existence might almost have been predicated upon general considerations.*

419. We have now to inquire whether the *power of generating Heat* is possessed by the Human subject in an equal degree at all ages; this question being very different from that of the *ordinary temperature* of the body at the various periods of life; since an individual who can maintain a high temperature when the surrounding air is moderately warm, may have very little power of bearing continued exposure to severe cold. Important analogical evidence on this point has been supplied by the experiments of Dr. W. F. Edwards upon the lower Mammalia, Birds, &c.† It appears from these to be a general fact, that, the younger the animal, the less is its independent calorifying power. Thus the development of the embryo of all Oviparous animals is entirely dependent upon the amount of external warmth supplied to it. There are many kinds of Birds, which, at the time they issue from the egg, are so deficient in the power of generating heat, that their temperature rapidly falls when they are removed from the nest and placed in a cold atmosphere; it being shown by collateral experiments, that the loss of heat was not to be attributed to the absence of feathers, nor to the extent of surface exposed in comparison with the bulk of the body; and that nothing but an absolute deficiency in the power of generating it, would account for the fall of temperature. This is quite conformable to facts well ascertained in regard to Mammalia. The fœtus, during intra-uterine life, has little power of keeping-up its own temperature; and in many cases it is much dependent on external warmth for some time after birth. The degree of this dependence, however, differs greatly in the various species of Mammalia, as among Birds; being less, in proportion as the general development is advanced. Thus, young Guinea-pigs, which can run-about and pick-up food for themselves almost as soon as they are born, are from the first independent of parental warmth; whilst on the other hand, the young of Dogs, Cats, Rabbits, &c., which are born blind, and which do not for a fortnight or more acquire the same development with the preceding, rapidly lose their heat when withdrawn from contact with the body of the mother.

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* See the Author's Memoir 'On the Mutual Relations of the Vital and Physical Forces,' in "Phil. Trans.," 1850.

† "On the Influence of Physical Agents on Life," part iii. chap. i.

420. In the Human species, it is well known that external warmth is necessary for the Infant, its body rapidly losing heat when exposed to the chilling influence of a low temperature; but the fact is too often neglected (under the erroneous idea of ‘hardening’ the constitution) during the early years of childhood. It is to be carefully remembered, that the development of Man is slower than that of any other animal, and that his calorifying power is closely connected with his general bodily vigour; and though the infant becomes more independent of it as development advances, it is many years before the standard can be maintained without assistance, throughout the ordinary vicissitudes of external temperature. Especial care is required with regard to the maintenance of the bodily heat by artificial warmth, in the case of children prematurely born; for the earlier the period of embryonic life, the less is the power of calorification that exists for some time after birth. The temperature of a seven months' child, though well swathed and near a good fire, was found by Dr. W. Edwards, within two or three hours after its birth, to be no more than 89·6°. And in some of the recorded instances in which the birth has taken place before the completion of the sixth month, it has not been found possible to maintain the warmth of the infant by exposure to the radiant heat of a fire, the contact of the warm body of another person being the only effectual means of keeping up its temperature.—The fullest measure of calorifying power is possessed by adults; but even in them it is sometimes weakened by previous exertion, so that death by the cooling of the body may occur, when the body is exposed to cold of no great intensity, but in a state of exhaustion of nervous power; a fact which remarkably confirms the views advanced in the preceding paragraph. A decrease of calorifying power takes place in advanced age. Old people complain that their "blood is chill;" and they suffer greatly from exposure to cold, the temperature of the whole body being lowered by it.

421. These facts have a very interesting connection with the results of statistical inquiries, as to the average number of deaths at different seasons; the following are recorded by M. Quetelet,* as occurring at Brussels, the *mean* monthly mortality at each age being reckoned as 100.

	First Month.	2—3 Years.	8—12 Years.	25—30 Years.	50—65 Years.	90 Years and above.
January	1·39	1·22	1·08	1·05	1·30	1·58
February	1·28	1·13	1·06	1·04	1·22	1·48
March	1·21	1·30	1·27	1·11	1·11	1·25
April	1·02	1·27	1·34	1·06	1·02	0·96
May	0·93	1·12	1·21	1·02	0·93	0·84
June	0·83	0·94	0·99	1·02	0·85	0·75
July	0·78	0·82	0·88	0·91	0·77	0·64
August	0·79	0·73	0·82	0·96	0·85	0·66
September . . .	0·86	0·76	0·81	0·95	0·89	0·76
October	0·91	0·78	0·76	0·93	0·90	0·74
November. . . .	0·93	0·91	0·80	0·97	1·00	1·03
December	1·07	1·01	0·96	0·97	1·15	1·29

‘ Essai de Physique Sociale," tom. i. p. 197.

We see from this table that, during the first months of infant life, the external temperature has a very marked influence; for the average mortality during each of the three summer months being 80, that of January is nearly 140, and the average of February and March is 125. This is confirmed by the result obtained by MM. Villermé and Milne-Edwards, in their researches on the mortality of the children conveyed to the Foundling Hospitals in the different towns in France; for they not only ascertained that the mortality is much the greatest during the first three months in the year, but also that it varies in different parts of the kingdom, according to the relative severity of the winter.* As childhood advances, however, the winter mortality diminishes, whilst that of the spring undergoes an increase; this is probably due to the greater prevalence of certain epidemics at the latter season; for the same condition is observed, in a still more remarkable degree, between the ages of 8 and 12 years,—the time when children are most severely affected by such epidemics. As the constitution acquires greater vigour, and the bodily structure attains its full development, the influence of the season upon mortality becomes less apparent; so that at the age of from 25 to 30 years, the difference between the summer and winter mortality is very slight. The difference reappears, however, in a very marked degree, at a later period, when the general vigour, and the calorifying power, undergo a gradual diminution. Between the ages of 50 and 65, it is nearly as great as in early infancy; and it gradually becomes more striking, until, at the age of 90 and upwards, the deaths in January are 158, for every 74 in July (a proportion of 2½ to 1); and the average of the three winter months is 145, whilst that of the three summer months is only 68, or less than one-half.—The results of the comparisons which have now been carried-out for many successive years, in the Reports of the Registrar-General, between the variations in the weekly rate of mortality in the Metropolis and the range of atmospheric temperature, present a close coincidence with the foregoing: it being especially to be noted, that the rate of mortality (save during the prevalence of any fatal epidemic) is almost invariably the highest during the winter months; that the increase of deaths at that period is most marked amongst children and old people; and that any extraordinary severity of winter cold constantly produces a great augmentation in the mortality, the weekly number of deaths rising from the average of 1100 (or thereabouts) to 1600 or even 1800, when the mean temperature of the week remains six or eight degrees below the freezing-point.

422. Having thus considered the means by which the degree of Heat, necessary for the performance of the functions of the Human system, is generated, we have to inquire how its temperature is prevented from being raised too high; in other words, what *frigorifying* means there are, to counterbalance the influence of causes, which in excess would other-

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* Dr. Emerson has shown that, in the Southern and Middle States of North America, the *high summer* temperature is the greatest cause of Infant-mortality; the proportion of deaths during the first year of childhood, occurring in the months of June, July, and August, being about *four* times greater than that occurring during the same months in any subsequent year up to the age of 20. The *winter* mortality under the second year scarcely exceeds the average of subsequent years. ("Amer. Jour. of Med. Sci.," Nov. 1831.)

wise be fatal, by raising the heat of the body to an undue degree (§ 430). How is it, for example, that, when a person enters a room whose atmosphere is heated to one or two hundred degrees above his body, the latter does not partake of the elevation, even though exposed to the heat for some time? Or, since the inhabitants of a climate, where the thermometer averages 100° for many weeks together, are continually generating additional heat in their own bodies, how is it that this does not accumulate, and raise them to an undue elevation?—The means provided by Nature for cooling the body when necessary, are of the simplest possible character. From the whole of its soft moist surface, simple *Evaporation* will take place at all times, as from an inorganic body in the same circumstances; and the amount of this will be regulated merely by the condition of the atmosphere, as to warmth and dryness. The more readily watery vapour can be dissolved in atmospheric air, the more will be lost from the surface of the body in this manner. In cold weather, very little is thus carried-off, even though the air be dry: and a warm atmosphere, already charged with dampness, will be nearly as ineffectual. But simple evaporation is not the chief means by which the temperature of the body is regulated. The Skin, as already mentioned (§ 339), contains a large number of glandulæ, the office of which is to secrete an aqueous fluid; and the amount of this *Exhalation* appears to depend solely or chiefly upon the *temperature* of the surrounding air. Thus, when the external heat is very great, a considerable amount of fluid is transuded from the skin; and this, in evaporating, carries-off a large quantity of the free caloric, which would otherwise raise the temperature of the body. If the atmosphere be hot and dry, and also be in motion, both exhalation and evaporation go-on with great rapidity. If it be cold, both are checked, the former almost entirely so; but, if it be dry, some evaporation still continues. On the other hand, in a hot atmosphere saturated with moisture, exhalation continues, though evaporation is almost entirely checked; and the fluid poured-out by the exhalant glands accumulates on the skin. There is reason to believe that the secretion continues even when the body is immersed in water, provided its temperature be high.—We learn from these facts the great importance of not suddenly checking Exhalation, by exposure of the surface to cold, when the secretion is being actively performed; since a great disturbance of the circulation will be likely to ensue, similar to that which has been already mentioned, as occurring when other important secretions are suddenly suspended.

3. *Evolution of Light.*

423. Although the evolution of Light from the living Human subject is an exceptional phenomenon, which has only been observed in morbid states of the body, yet its occasional occurrence is fraught with interest to the Physiologist, on the one hand from its relation to the Luminosity so common among the lower animals, and on the other from the indications which it affords of the possibility of the formation, even during life, of peculiar phosphuretted compounds, which, being products of incipient decomposition, have been usually supposed to be generated only after death.—There is no doubt that luminous exhalations frequently ascend

from burial-grounds; and that the superstitions of many nations respecting 'corpse-lights' have to this extent a foundation in fact. A very decided luminosity has been observed to proceed from dissecting-room subjects, the light thus evolved being sufficient to render the forms of the bodies, as well as those of muscles and other dissected parts (which are peculiarly bright), almost as distinct as in the daylight. That this proceeds from the production of a peculiar phosphorescent compound, is shown by the fact, that the luminosity may be communicated to the fingers or to towels, &c., by contact with the luminous surfaces.*—Dr. W. Stokes narrates the case of a patient who was under his observation, some years since, in the Old Meath Hospital, having been admitted on account of an enormous cancer in her breast, which was in an advanced stage of ulceration, the edges being irregular and everted; every part of the base and edges of this cavity was strongly phosphorescent, the light being sufficient to enable the figures on a watch-dial to be distinguished within a few inches; and here also it appeared that the luminosity was due to a particular exudation from the exposed surface. Three cases are recorded by Sir H. Marsh, in which an evolution of light took place from the living body, without any such obvious source of decomposition; all the subjects of these cases, however, were in the last stage of phthisis; and it can scarcely be doubted that here, as in other diseases of exhaustion, incipient disintegration was taking-place during the later periods of life (§ 60). The light in each case is described as playing around the face, but not as directly proceeding from the surface; and in one of these instances, which was recorded by Dr. D. Donovan,† not only was the luminous appearance perceptible over the head of the patient's bed, but luminous vapours passed in streams through the apartment. It can scarcely be doubted that it was here the *breath* which contained the luminous compound, more especially as it was observed in one of the cases to have a very peculiar smell; and the probability that the luminosity was due to the presence of phosphorus in progress of slow oxidation, is greatly increased by the fact already referred-to (§ 294), that the injection of phosphuretted oil into the blood-vessels gives-rise to a similar appearance. In repeating this experiment, Sir H. Marsh states that when half an ounce of olive-oil, holding two grains of phosphorus in solution, was injected into the crural vein of a dog, a dense white vapour began to issue from the nostrils even before the syringe was completely emptied, which became faintly luminous on the removal of the lights: and the injection being repeated with the same quantity, the expiration immediately became beautifully luminous, resembling jets of pale-coloured flame pouring-forth from the nostrils of the animal. And the luminosity which has been occasionally observed in the urine,‡ may fairly be imputed to an increase in the quantity of unoxidized phosphorus which it seems normally to contain; its liberation taking-place at a more rapid rate than its conversion into phosphoric acid, either through excessive excretion or through impeded respiration.* A case has been recorded by Kaster (loc. cit.) in which the body-linen was rendered luminous by the perspiration, after any violent exercise; and here, too, the cause may be presumed to have been the same.—On the whole, then, we may conclude the occasional evolution of Light from the Human subject, to be the consequence (when not an *electrical* phenomenon) of the production of a phosphorescent compound at the expense of the disintegrating tissues; which compound passes-off through one of the ordinary channels of excretion.

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* See Sir Herbert Marsh on "The Evolution of Light from the Living Human Subject" (Dublin, 1842), p. 20.—From this interesting pamphlet, most of the statements in this paragraph are derived.

† "Dublin Medical Press," Jan. 15, 1840.

‡ "Casper's Wochenschrift," 1849, No. 15.—A case has been recently put on record ("Büchner's Repert.," B. viii. p. 342), in which the urine and semen of a patient who was under treatment for impotence and spermatorrhœa, and who was employing phosphorus as a remedy both internally and externally, were observed to be luminous.

4. *Evolution of Electricity.*

424. When the vast variety of changes of condition to which the components of the living body are subjected during the performance of its vital operations, and the impossibility of the occurrence of any of these without some disturbance of Electric equilibrium,† are duly considered, the wonder is, not that such disturbance should be occasionally so considerable as to make itself apparent, but that it should be ordinarily so obscure as only to be detected by the most careful search, and with the assistance of the most delicate instruments. The researches of Prof. Matteucci, M. du Bois-Reymond, and others, however, have now made it apparent, that there are no two parts of the body (save those which correspond on the opposite sides), whose electrical condition is precisely the same; and that the differences between them are greater in proportion to the diversity of the vital processes which are taking-place in them, and to the activity with which these are being carried-on.‡—It is by the comparison of the electric states of different Secreting surfaces, that such departures from equilibrium are most readily demonstrated. Thus, Donné found that the skin and most of the internal membranes are in opposite electrical states; and Matteucci observed a considerable deflec-

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* The large proportion of intemperate subjects, among those who exhibit this phenomenon, seems to confirm the view already expressed, that the habitual presence of Alcohol in the blood interferes with the oxidation and elimination of excrementitious matters.

† There is probably no instance of *chemical union* or decomposition, in which the Electric condition of the bodies concerned is not altered. Simple *change of form*, from solid to liquid, or from liquid to gaseous, is attended with electric disturbance; and this is greatly increased when any separation takes place between substances that were previously united, as when water containing a small quantity of saline matter is caused to evaporate and to leave it behind. *Heat*, again, is continually generating Electricity; for not only is a current produced by the heating of two dissimilar metals in contact, but also by the unequal heating of two parts of the same bar; and though the effect is most striking in the case of metals, it is by no means limited to them. And so constantly is Electricity generated by the retardation of *motion*, as in friction, that it is not possible to rub-together any two substances, excepting those which are of the most perfect homogeneity (such as the fractured surfaces of a broken bar), without the production of Electric change, as well as of Heat.

‡ Having had an opportunity of witnessing some of the experiments made by M. du Bois-Reymond with a magneto-electrometer of extraordinary sensitiveness, the Author can bear his personal testimony to the fact, that the electricity even of the corresponding fingers of the two hands is very seldom equally balanced, and that the existence of even the slightest scratch or abrasion of surface upon one of them produces a very marked disturbance.

tion of the needle of a delicate galvanometer, when the liver and stomach of a rabbit were connected with its platinum electrodes.* More recently, Mr. Baxter has found that if one of the electrodes be placed upon any part of the intestinal surface, and the other be inserted into the branch of the mesenteric vein proceeding from it, a decided deflection of the needle was produced, indicating a positive condition of the blood; but that no effect was produced, when the second electrode was inserted into the artery of the part, instead of into its vein. These effects were found to cease after the death of the animals; and could not be attributed, therefore, to mere chemical differences between the blood and the secreted product; but must have arisen from electric disturbance taking-place in the very act of secretion.† Scoutetten, again, has found arterial blood to be positive in its relations to venous blood.—That the process of Nutrition, as well as of Secretion, in parts which are undergoing rapid molecular change, gives-rise to electric disturbance, is proved by the experiments of Matteucci and Du Bois-Reymond, upon the relative electrical states of different parts of muscles and nerves. If the two extremities of a Muscle, removed from the body of an animal very recently killed, be applied to the two electrodes of a delicate galvanometer, there is usually some deflection of the needle; this being greater, in proportion to the difference in the arrangement of the muscular and tendinous elements at the two extremities. Although the direction of the current is constant for each muscle, yet there is no constant relation between the direction of the currents and the position of the muscles in the body; thus in the *gastrocnemius* of the Frog's leg, the direction is from the foot towards the body, whilst in the *sartorius* it is the reverse. Taking all the muscles of a part together, however, there is usually such a want of balance between the opposite currents, that a constant current is established in the direction of the strongest and most numerous of the separate muscular currents; this, in the Frog, passes uniformly from the hind-feet towards the head, and was at one time supposed to be peculiar to that animal; but a similar current may almost always be detected in other animals. The muscular current grows feebler and feebler, the longer the muscle has been removed from the body; it is affected by any agents which tend to lower its vitality, and becomes extinct as soon as its contractility ceases. From the experiments of M. du Bois-Reymond, it may be concluded that the current in the arm of Man, when at rest, is from the shoulder towards the points of the fingers. (The special conditions of the 'Nervous' and 'Muscular' currents will be hereafter fully considered in the chapters devoted to the Nerves and Muscles respectively.)

425. Some of the most important parts of the body being thus in a state of constant *disequilibrium* with regard to each other, it is not surprising that the Electric state of the whole should be ordinarily in disequilibrium with that of surrounding bodies. This difference, however, is usually prevented from manifesting itself, in consequence of the restoration of the equilibrium by the free contact which is continually taking-place between them; and it is for the most part only when the Human body is insulated, that it becomes apparent. The galvanometer is then affected, however, by the contact of one of its electrodes with the person

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* See M. Becquerel's "Traité de l'Electricité," tom. i. p. 327, and tom. iv. p. 309.

† "Philosophical Transactions," 1848, p. 243.

insulated, and the other with any neighbouring uninsulated body; and also by the contact of the electrodes with the hands of two persons both insulated, who join their other hands together, a difference in the electrical states of the two individuals being thus indicated. The electricity of Man is most commonly positive, and irritable men of sanguine temperament have more free electricity than those of phlegmatic character. The electricity of women is more frequently negative than that of men. There are persons who scarcely ever pull off articles of dress which have been worn next the skin, without sparks and a crackling noise being produced; especially in dry weather, when the electricity of the body is retained, instead of being rapidly dissipated as it is by a damp atmosphere. The effect is usually heightened, if silk stockings and other silken articles have been worn, since these act as insulators. It is doubtless in part attributable to the friction of the articles of dress against each other and against the body; but we can scarcely doubt that it is partly due to the generation of electricity in the body itself, since it bears no constant relation to the former of these supposed causes. Thus a Capuchin friar is mentioned by Dr. Schneider,* who, on removing his cowl, always found a number of shining crackling sparks to pass from his scalp; and this phenomenon continued still perceptible after a three weeks' illness.—The most remarkable case of the generation of Electricity in the Human subject at present known, was recorded some years since in America.† The subject of it, a lady, was for many months in an electric state so different from that of surrounding bodies, that whenever she was but slightly insulated by a carpet or other feebly-conducting medium, sparks passed between her person and any object she approached; when most favourably circumstanced, four sparks per minute would pass from her finger to the brass ball of the stove at the distance of 1½ inch. From the pain which accompanied the passage of the sparks, her condition was a source of much discomfort to her. The circumstances which appeared most favourable to the generation of the electricity, were an atmosphere of about 80°, tranquillity of mind, and social enjoyment; whilst a low temperature and depressing emotions diminished it in a corresponding degree. The phenomenon was first noticed during the occurrence of an Aurora Borealis; and though its first appearance was sudden, its departure was gradual. Various experiments were made, with a view of ascertaining if the electricity was generated by the friction of articles of dress; but no change in these seemed to modify its intensity.

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* "Casper's Wochenschrift," 1849, No. 15.

† "American Journal of Medical Sciences," January, 1838.

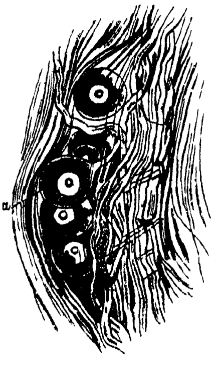
CHAPTER XI.

OF THE FUNCTIONS OF THE CEREBRO-SPINAL NERVOUS SYSTEM.

1. *General Summary.*

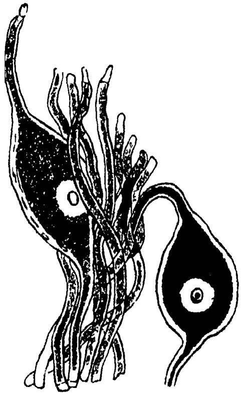
426. The Nervous System of Man, like that of all other Animals, is composed of *ganglionic centres* and *nerve-trunks;* the former being essentially composed of 'vesicular substance,' made-up of cells which may be spheroidal, fusiform, caudate, stellate, or of almost any variety of shape; the latter consisting entirely of 'nerve-fibres,' which, in their most completely-developed state, are tubular. All our knowledge of the structure and endowments of these two forms of tissue, renders it probable that they bear a *complementary* relation to each other; the Vesicular substance having for its office to *originate* changes, which it is the function of the Fibrous to *conduct.* And thus, by means of the extensive ramifications of the nerve-trunks, and the power of instantaneous transmission which they possess, almost every part of the body is brought into such close relation with the central Sensorium, that impressions made even at the points most remote from it are immediately felt there (provided the nervous communication be perfect); while the influence of Mental states in determining movements, is exerted no less speedily and surely upon the muscular apparatus. For the transmission of these two sets of impressions, the 'centripetal' and the 'centrifugal,' two distinct sets of fibres are provided, neither of which is capable of taking-on the function of the other; these are termed respectively, the *afferent* and the *efferent.** Of

FIG. 88.



Microscopic Ganglion from Heart of Frog, showing at *a*, a *Unipolar Ganglionic Cell.*

FIG. 89.



Bipolar Ganglionic Cells and nerve-fibres from ganglion of 5th Pair in Lamprey.

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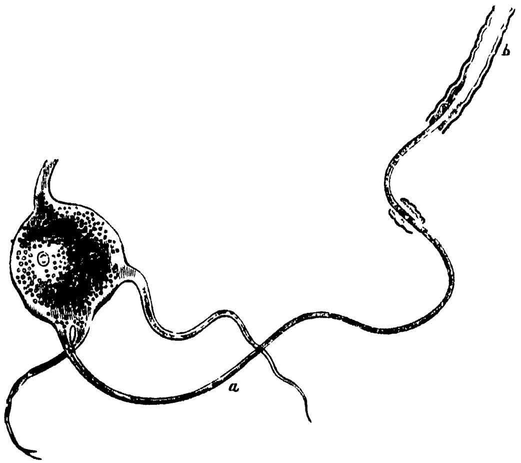
* The 'afferent' nerves are commonly designated *sensory;* but this is not strictly correct, since they frequently convey impressions which do not give rise to sensations. The 'efferent' nerves, in like manner, though generally *motor*, are by no means necessarily so.

the mode in which the former terminate in the central organs towards which they pass, and in which the latter commence their course in these same organs, no general statement can as yet be made; but it is quite certain that, in many instances at least, there is an absolute continuity from one form of nerve-tissue to the other. Three principal modes have been ascertained, in which this may occur. Either a globular cell may give-off a single prolongation that becomes a fibre, as seen at *a*, Fig. 88; in which case the cell is said to be 'unipolar.' Or a ganglion-cell presents itself (as it were) in the course of a nerve-tube, having each of its extremities prolonged into a fibre, as shown in Fig. 89; in which case the cell is said to be 'bipolar.' The former of these arrangements seems to be more common in the nervous centres of Man and the higher Vertebrata; whilst the latter prevails in Fishes. But in certain parts of the nervous centres of Man, we meet with ganglionic cells sending-out radiating prolongations to the number of three, four, five, six, or more; some of which are occasionally to be traced into continuity with the axis-cylinders of nerve-tubes, as seen at *a*, *b*, Fig. 90; whilst others, it is probable, inosculate with those of other stellate cells. Dr. Beale* has adduced strong evidence, derived from microscopic investigation with high power, that all nerves primarily originate in ganglionic cells; that such cells, without exception, are connected with, or pass into, fibres; and that there are no free nerve-cells whatever: and he is of opinion that many anatomical facts may be brought forward, rendering it very probable that a fibre passing *from* a cell in a nervous centre, returns *to* the same cell; and thus that, however long and circuitous its course, and however

FIG. 90.



Stellate Ganglionic Cell, from 'substantia ferruginea' of Human Brain; one of its prolongations, *a*, becoming continuous with the axis-cylinder of a double-contoured nerve-fibre, *b*.

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* "Archives of Medicine," vol. iii. p. 234.

numerous its connections with other cells and fibres may be, a complete and uninterrupted *circuit* may be shown to be constantly present.*

427. *Regeneration of Nervous Structure.*—If a nerve be divided by a sharp instrument, and the ends placed in apposition, they will rapidly reunite, with complete restoration of function. The union is accomplished by the effusion of lymph containing nuclei,† which become connected by fibres that ultimately form the axis cylinders of new nerves; the medullary sheath being subsequently developed around them. It is questionable whether, after extirpation of a ganglion, new ganglionic corpuscles can be formed; yet, in Brown-Séquard's experiments upon pigeons, it was found that the whole spinal cord would reunite after division, with almost complete restoration of function. The distal extremities of nerves separated from their centres by section undergo fatty degeneration.‡ Various experimenters have sought to determine whether a sensory nerve can be made to convey motor impulses, and *vice versâ.* For this purpose, no nerves are more conveniently situated than the hypoglossal and lingual branch of the Fifth. If these be divided, and the peripheric extremity of the hypoglossal nerve be placed in apposition with the outer extremity of the lingualis, in a few weeks union will have occurred; and although the muscles may be excited to contract by an electrical current applied to the lingualis or sensory nerve, yet there is total loss of voluntary control over the lingual muscles; and if the operation be performed on both sides, the animal is rendered permanently incapable of protruding its tongue.§ Yet Philippeaux and Vulpian‖ draw the conclusion from their experiments, that when the properties of the hypoglossal nerve have been abolished by section, after the lapse of some time the lingualis acquires motor powers which it did not previously possess.

428. The *chemistry* of the Nerves has hitherto received but little attention at the hands of Chemists. The Brain contains about 75 per cent of water, and 25 of solid residue, of which about 15 parts consist of fatty substances, 7·5 of albuminous compounds, 1·5 of salts, and 1 of extractive matters. The proportions of these constituents, however, are different in other parts of the nervous system; the amount of water, for instance, varying from 70 to 85 per cent. The fat contained in the grey matter is always much smaller than that in the white. 100 parts of the fatty substances consist, according to v. Bibra, of 30 parts of Cerebrin, 20 of Cholesterine, and 50 of other oleaginous substances, including Oleo- and Glycero-phosphoric acids, Lecithin, Olein, and Palmitin, and the Oleic and Palmitic acids. Besides these, v. Gorup-Besanez¶ enumerates an albuminous substance resembling Syntonin, a substance analogous to Elastin, small quantities of a soluble albuminous substance, Inosite, Sarkin, Xanthin, Creatin, Lactic, Uric, and Phosphoric acids, and their combinations with Potash, Lime, and Magnesia; Silicic Acid, Oxide of Iron, small quantities of Alkaline Sulphates, and lastly, Chloride of

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* We shall hereafter see, however, in considering the distribution of Nerve in voluntary muscle, that the last proposition is, to say the least, very doubtful.

† Hjelt-Otto, "Virchow's Archiv," xix. p. 352.

‡ See Schiff, "Physiologie," p. iii.

§ See the experiments of Gluge and Thiernesse, in Brown-Séquard's "Journ. de la Physiologie," 1859, vol. ii. p. 686; also those of Philippeaux and Vulpian, "Comptes Rendus," 1860, ii. p. 363, and 1863, p. 58.

‖ "Archiv. Gén. de Méd.," July 1863, p. 122.

¶ "Phys. Chem.," p. 624.

Sodium. The quantity of Phosphorus is very large, amounting, according to Borsarelli,* to from 1·352 to 1·790 per cent.

429. As regards the general relations of the principal Centres of the Nervous System of Man, it is only requisite here to remark, that those which make-up the Cerebro-Spinal portion of the apparatus have such an intimate structural relation to each other, and so much more frequently act consentaneously than separately, that, notwithstanding the abundant evidence of the diversity of their respective endowments, there is considerable difficulty in the determination of their special functions; since the destruction or removal of any one portion of the Nervous system, not only puts a stop to the phenomena to which that portion is directly subservient, but so deranges the general train of nervous activity, that it often becomes impossible to ascertain, by any such method, what is its real share in the entire performance.—In this difficulty, however, we may advantageously have recourse to the study of the structure and actions of those forms of the Nervous System presented to us among the lower animals, in which its ganglionic centres are fewer and less intimately connected, and in which, therefore, it is more easy to gain an acquaintance with their several endowments. And from an extensive survey of these, we seem able to deduce the following conclusions, which afford the most valuable guidance in the study of the Nervous System of Man:†—

I. The Nervous System, in its lowest and simplest form, may consist of but a single ganglionic centre,‡ with afferent and motor nerves, whose function is essentially *internuncial;* impressions made upon the afferent fibres exciting respondent or 'reflex' movements in the muscles supplied by the motor, without any necessary intervention of consciousness.—Such movements are properly distinguished as *excito-motor.*

II. A simple repetition of such ganglionic centres may exist to any extent, without heterogeneousness of function, or any essential departure from the mode of action just indicated; each of these centres may be specially connected by afferent and motor fibres with one segment or division of the body, and may minister peculiarly to *its* actions; but the several centres may be so intimately connected by commissural fibres, that an impression made upon the afferent nerves of any one of them may excite respondent motions in other segments.—This we see effected through the annular gangliated cord of the higher Radiata, and through the longitudinal gangliated cord of the Articulata; the disposition of the ganglia and of their connecting cords, having reference simply to the general plan of the body.

III. A higher form of Nervous System is that in which the multiplication of ganglionic centres has reference, not to the multiplication of similar parts which are to be alike supplied with nervous power, but to the exercise of a diversity of functions, through the instrumentality of different structures: thus, in the higher Articulated and Molluscous tribes, we find ganglionic centres specially set apart for the actions of deglutition and respiration, as well as for those of locomotion; but their *modus operandi* is still the same, these actions being all 'excito-motor,' that is, being performed through the 'reflex' agency of their several ganglionic centres, without the necessary intervention of consciousness. These centres are connected with each other commissurally, when they are required to act with consentaneousness; and it is frequently to be observed in the most developed forms of each type, that they come into actual coalescence, their functional distinctness being still indicated, however, by the distribution of their nerve-trunks.

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* "Syd. Soc. Year-Book," 1861, p. 32.

† For a general view of the facts on which these conclusions are based, see "Princ. of Comp. Phys.," chap. xiii.

‡ It may, perhaps, be doubted whether any Animal really exists, possessing such a nervous system, and yet not endowed with consciousness. It is quite certain, however, that animals do exist (the Tunicated Mollusca for example), in which the actions above referred-to are the only ones of which we have any distinct evidence from observation of their habits.

IV. In all but the very lowest Invertebrata, the Nervous System includes, in addition to the foregoing, certain ganglionic centres, situated in the neighbourhood of the entrance to the digestive cavity, and connected with organs, which, from their more or less close resemblance to our own instruments of special sense, we conclude to be organs of sight, smell, hearing, &c. Now as we know from our own experience, that impressions made upon these organs produce no influence on our actions unless we become *conscious* of them, and as the Invertebrata possess no distinct ganglionic centres of a higher character, it seems to be a legitimate inference, that these 'sensorial' ganglia are the instruments by which the animals furnished with them are rendered cognizant of such impressions, and through which the sensations thus called into existence serve to prompt and direct their movements. What is commonly designated as the 'brain' of Invertebrata (more properly their 'cephalic ganglia') cannot be shown to consist of anything else than an assemblage of *sensorial* centres; and its actions appear to be entirely of a 'reflex' character, such of the movements of these animals as are not excito-motor, being performed (there is strong reason to believe) in direct respondence to sensations excited by internal or external impressions. Such movements, therefore, may be designated as *sensori-motor*, or *consensual*. Like the preceding, they do not appear to involve the participation either of Emotion, Reason, or Will; and the proportion which they bear to the actions of the excito-motor kind, seems to correspond pretty closely with the relative development of the cephalic ganglia and of the rest of the nervous system, as is very obvious when the larva and imago states of Insects are compared.—However disjointed the various 'excito-motor' centres may be amongst each other, we uniformly find them connected with the 'sensory' ganglia by commissural tracts; and this anatomical fact, with many phenomena which observation and experiment upon their actions have brought to light, makes it apparent, that besides the reflex actions which are performed through their own direct instrumentality, the sensory ganglia have a participation in those performed through other ganglionic centres. Thus it seems probable that a stimulus transmitted downwards from the sensory ganglia, to one of the ganglia of the trunk of a Centipede, excites the efferent nerves of that ganglion to call into contraction the muscles supplied by them, just as the excitor influence arriving at that ganglion through its own afferent nerves would do.

430. The whole Nervous System of Invertebrated Animals, then, may be regarded as ministering entirely to *purely-reflex* action; and its highest development, as in the class of Insects, is coincident with the

highest manifestations of the 'instinctive' powers, which, when carefully examined, are found to consist entirely in movements of the excito-motor and sensori-motor kinds. When we attentively consider the habits of these animals, we find that their actions, though evidently adapted to the attainment of certain ends, are very far from evincing a *designed* adaptation on the part of the beings that perform them, such as that of which we are ourselves conscious in our own voluntary movements, or which we trace in the operations of the more intelligent Vertebrata. For in the first place, these actions are invariably performed in the same manner by all the individuals of a species, when the conditions are the same; and thus are obviously to be attributed rather to a uniform impulse, than to a free choice; the most remarkable examples of this being furnished by the economy of Bees, Wasps, and other 'social' Insects, in which every individual of the community performs its appropriate part, with the exactitude and method of a perfect machine. The very perfection of the adaptation, again, is often of itself a sufficient evidence of the unreasoning character of the beings which perform the work; for, if we attribute it to their own intelligence, we must admit that this intelligence frequently equals, if it does not surpass, that of the most accomplished Human reasoner.* Moreover, these operations are performed without any guidance from experience; for it can be proved in many cases, that it is impossible for the beings which execute them to have received any instruction whatever; and we see that they do not themselves make any progressive attempts towards perfection, but that they accomplish their work as well when they first apply themselves to it, as after any number of repetitions of the same acts. It is interesting to observe, moreover, that as these instinctive operations vary at different periods of life, so there is a corresponding variation in the structure of the Nervous system. Thus we see that, in the *larva* of the Insect, these operations are entirely directed towards the acquisition of food; and its organs of sense and locomotive powers are only so far developed as to serve this purpose. But in the *imago* or perfect Insect, the primary object is the continuance of the race; and the sensorial and motor endowments are adapted to enable the individual to seek its mate, and to make preparations (frequently of a most elaborate kind) for the nurture of the offspring.—Hence we can scarcely fail to arrive at the conclusion, that the *adaptiveness* of the instinctive operations of Insects, &c., lies in the original construction of their nervous system, which causes particular movements to be executed in direct respondence to certain impressions and sensations. And this view is confirmed by the comparison of such movements with those which, in the Human subject, are most directly concerned in the maintenance of the life of the individual, and in the perpetuation of the race. For we have the evidence of our own consciousness in regard to these, that, however obvious their *purpose* may be, and however complete their *adaptation* to that purpose, they are performed, *not* with any notion of that purpose, but at the prompting of an irresistible impulse, which is not only independent of all intelligent appreciation of the result, but may produce its effect without even affecting the consciousness of the agent. Thus the infant seeks the nipple, and puts its muscles into suctorial action, without any knowledge, derived from experience,* that by so doing it will relieve the uneasy feeling of hunger; and if we could imagine a man coming into the world with the full possession of all his faculties, we may feel tolerably certain that he would not wait to eat until he had learned by experience his dependence upon food. We shall see that adult animals whose Cerebral hemispheres have been removed, will eat food that is put into their mouths, although they will not go to seek it; and this is the case with many Human idiots. When the functions of the Brain are disturbed, or in partial abeyance, as in fever, we often observe a remarkable return to the instinctive propensities in regard to food; and the Physician frequently derives important guidance with respect to the patient's diet and regimen (particularly as to the administration of wine), from the inclination or disinclination which he manifests. So, in regard to the intercourse of the sexes, the impulse which prompts to it does not arise from a knowledge of the ultimate purposes which it is designed to answer; and the higher powers of the mind are only so far concerned in it, that when the action of the instinctive impulse has led to the formation of a definite idea of the object of desire, the Intelligence is prompted to take means for its gratification.*

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* See "Princ. of Comp. Phys.," 4th edit., p. 694.

431. Thus, then, the type of psychical perfection among Invertebrated animals, which is manifested in the highest degree in the Social Insects, consists in the exclusive development of the Instinctive faculty; that is, of *automatic* powers of a very simple kind; in virtue of which, each individual performs those actions to which it is directly prompted by the impulses arising out of impressions made upon its afferent nerves, without any self-control or self-direction; so that it must be regarded as entirely a creature of necessity, performing its instrumental part in the economy of Nature from no design or will of its own, but in accordance with the plan originally devised by its Creator.

432. On turning to the Vertebrated series, on the other hand, we find that *its* type of psychical perfection—as shown in Man—consists in the highest development of the *Reason*, and in the supreme domination of the *Will*, to which all the 'automatic' actions, save those which are absolutely essential to the maintenance of the Organic functions, are brought under subjection; so that each individual becomes not only a thinking and reflecting, but a self-moving and self-controlling agent, whose actions are performed with a definite purpose which is distinctly before his own view, and are adapted to the attainment of their end by his own intelligence. This, however, is only true of Man in his most elevated state; and not only in ascending the Vertebrated scale, but also in watching the progressive evolution of *his* mental faculties during the earlier periods of his life, may we trace a regular gradation, from a condition but little

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* We have not, perhaps, any right to affirm that there is *nothing whatever* analogous in the Invertebrata to the Reasoning powers and Will of higher animals; but if these faculties have any existence among them, they must be regarded as in a merely rudimentary state, corresponding with the undeveloped condition of the Cerebrum. The only distinct indication of intelligence displayed by Invertebrata, is the slight degree of capacity of "learning by experience" which some of them display; this capacity being limited to the mere formation of *associations* between the psychical states called-up by different objects of sense, which we observe to be the first stage in the development of the mental powers in the Human infant.

(if at all) in advance of that of the higher Invertebrata, up to that which is displayed in the noblest examples of Humanity. Through the entire series, however, we perceive that the Excito-motor and Sensori-motor portion of the Nervous system (§ 435) constitutes its fundamental and essential part; serving not merely as the instrument whereby those actions are performed, which are as necessary among the higher animals as they are among the lower, for the maintenance of the Organic functions; but also as the immediate recipient of all those impressions from without, by which the higher operations of Mind are excited, and as the executant of the actions which proceed from them. But as we ascend the Vertebrated scale, or as we watch the progressive psychical development of the Infant, we find it becoming more and more obvious that the actions are prompted, not so much by simple sensations, as by *ideas* or notions of the objects to which they relate; these ideas being founded, in a large proportion of instances, upon the results of past experience, and the course of action being shaped in accordance with it. In the acts of animals of a still higher grade, as in those of the Child, we can scarcely fail to perceive the manifestation of *reasoning processes* analogous to those which we ourselves perform, and the expressions of some of those *emotional states* of which we are ourselves conscious. The superaddition of these more elevated endowments, in the Vertebrated series, is coincident with the addition of a peculiar ganglionic centre, the *Cerebrum*, to the Sensori-motor apparatus; and the relative proportion which the former bears to the latter, both as to size and to complexity of structure, corresponds so closely with the degree of predominance which the Intelligence possesses over the Instinctive propensities, that it is scarcely possible to doubt that the Cerebrum is the instrument through which this higher form of psychical power is exercised. Much of this exercise, however, may still be *automatic* in its nature; for so long as the current of thought and feeling flows-on in accordance with the direct promptings of Suggestion, and without any interference from Volition, may it be considered as a manifestation of the 'reflex' activity of the Cerebrum, which takes the form of a *mental instinct*. This reflex activity manifests itself not only in the psychical operations themselves, but also in muscular movements; and these, when they proceed from simple ideas without any excitement of feeling, may be designated as *ideo-motor;* whilst if they spring from a passion or emotion, they are termed *emotional*. The *mental* instincts, however, are by no means as invariable in the different individuals of the same species, as are what may be termed the *physical* Instincts of that inferior part of the nervous apparatus, which is more closely connected with the maintenance of the Organic life; the particular changes which any given suggestions will excite in each, being partly determined by original constitution, and partly by acquired habits.

433. The superiority of the Mind of Man over that of the most elevated among the lower animals, consists not only in the far greater variety and range of his faculties, but yet more in that dominant power of the Will, which enables him to utilize them with the highest effect. In so far as the course of his thoughts and feelings is the mere result of the action of external impressions upon an organization having certain respondent tendencies, must he be considered as irresponsible for his

actions, his character being formed *for* instead of *by* him: but in so far as he can exert a Volitional power of directing his thoughts and controlling his feelings, may he rise superior to circumstances, make the most advantageous use of the Intellectual faculties with which he may be endowed, and bring his Moral character more and more into accordance with the highest type which his nature may be capable of attaining in its present sphere of existence. Notwithstanding the evidences of rationality which many of the lower animals present, and the manifestations which they display of emotions that are similar to our own, there is no ground to believe that *they* have any such controlling power; on the contrary, all observation seems to lead to the conclusion, that they are under the complete domination of the ideas and emotions by which they may be for the time possessed, and have no power either of repressing these by a forcible act of Will, or of turning the attention, by a like voluntary effort, into another channel. In this respect, then, their condition resembles that of the Dreamer, the Somnambule, or the Insane patient, in all of whom this voluntary control is suspended, and who (when their minds are susceptible of external impressions) may be so 'played upon' by the suggestion of ideas, that any respondent action consistent with the ordinary mental state of the individual may be evoked by an appropriate stimulus; just as we see in the case of animals that are trained to the performance of particular sets of movements, which are executed in respondence to certain promptings conveyed to them through their sensorium. Now between the complete want of this controlling power of the Will, and the most perfect possession of it, every intermediate gradation is presented by the several individuals which make up the Human species; some persons being so much accustomed, in consequence of the weakness of their Will, to act directly upon the prompting of every transient impulse, that they can scarcely be said to be voluntary agents; and others allowing certain *dominant* ideas or *habitual* feelings to gain such a mastery over them, as to exercise that determining power which the Will alone ought to exert. This gradation may be perfectly traced in children, in whose education the development of the faculty of 'self-control' should be a leading object; and it is also displayed in certain phases of mental Imbecility, which result from a deficiency of the power of voluntarily fixing the attention upon any object of consciousness, and of thus withdrawing it either from external objects that tend to distract the mind, or from notions it has adopted which hold it in subjection.

434. When we apply ourselves to the study of the Cerebro-Spinal Nervous centres of Man, we find ourselves peculiarly liable to be misled by the great development which the Cerebrum presents, both as to size and to complexity of structure, in proportion to the other centres; and thus it has happened that, through the too exclusive attention commonly paid to *Human* Anatomy, the meaning of the facts brought to light by dissection has been very commonly misapprehended, and many of the physiological interpretations based upon them have been completely negatived by more extended inquiry.—It is only, in fact, by studying the Cerebro-Spinal apparatus in its lowest, as well as in its highest form, and by bringing the intervening grades into comparison with both extremes, that it is possible to establish what are its fundamental or essential, and what its accessory parts; and in this way only can such a corre-

spondence be established between the development of a particular structure and the manifestation of a psychical endowment, as may enable the latter to be attributed with any degree of probability to the former. In fact there is no part of the Human Organism, as to which the advantages of such a comparison are so striking, or in which the value of the "experiments ready prepared for us by Nature" is so much above that of the results of artificial mutilations.

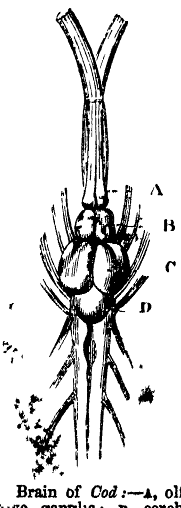
435. *Cerebro-Spinal Nervous Centres.*—Under the guidance, then, of these principles, we find that we may distinguish, as the fundamental part of the Cerebro-Spinal apparatus of Man, the *Cranio-Spinal Axis*, consisting of the Spinal Cord, the Medulla Oblongata, and the Sensory Ganglia, and altogether constituting the centre of automatic movement. —The Spinal Cord, consisting of a tract of vesicular matter enclosed within strands of longitudinal fibres, and giving-off successive pairs of intervertebral nerves which are connected at their roots with both of these components, is obviously homologous with the gangliated ventral column of the Articulata, chiefly differing from it in the continuity of the ganglionic substance which occupies its interior; and each segmental division of it, which serves as the centre for its own pair of nerves, may be considered, like each ganglion of the ventral column of the Articulata, as a repetition of the single 'pedal' or locomotive ganglion of the Mollusca.—The Medulla Oblongata consists of a set of strands, which essentially correspond with the cords that pass round the œsophagus in Invertebrated animals, connecting the cephalic ganglia with the first sub-œsophageal ganglion; but as the whole cranio-spinal axis in the Vertebrata lies *above* the alimentary canal (the trunk being supposed to be in a horizontal position), there is no such divergence of these strands, the only separation between them being that which is known as the 'fourth ventricle.' Interposed among the commissural fibres of the Medulla Oblongata, however, are certain collections of vesicular matter, which serve as the ganglionic centres for the movements of respiration and deglutition, and which thus correspond with the 'respiratory' and 'stomato-gastric' ganglia of Invertebrated animals. This incorporation of so many distinct centres into one system, would seem destined in part to afford to all of them the protection of the vertebral column; and in part to secure that consentaneousness of action and that ready means of mutual influence, which are peculiarly requisite in beings in whom the activity of the Nervous system is so predominant. Thus the close connection which is established in the higher Vertebrated animals between the respiratory and the general locomotive apparatus, is obviously subservient to the use which the former makes of the latter in the performance of its functions; whilst, on the other hand, the control which their encephalic centres possess over the actions of the respiratory ganglia, enables the Will to regulate the inspiratory and expiratory movements in the manner required for the acts of vocalization.—Under the term Sensory Ganglia, may be comprehended that assemblage of ganglionic masses lying along the base of the skull in Man, and partly included in the Medulla Oblongata, in which the nerves of the 'special senses,' Taste, Hearing, Sight, and Smell, have their central terminations; and with these may probably be associated the two pairs of ganglionic bodies known as the Corpora Striata and Thalami Optici, into which may be

traced the greater proportion of the fibres that constitute the various strands of the Medulla Oblongata, and which seem to stand in the same kind of relation to the nerves of Touch or 'common sensation,' that the Olfactive, Optic, Auditory, and Gustative ganglia bear to *their* several nerve-trunks.

436. Now it is not a little interesting, that this Cranio-Spinal axis, which represents in Vertebrated animals the whole nervous system of the Invertebrata (with the exception of the rudiment of the Sympathetic which they possess), should exist in the lowest known Vertebrated animal without any superaddition, and should be sufficient for the performance of all its actions. Such is the case in the curious *Amphioxus*, a little fish which presents not the slightest trace of either Cerebrum or Cerebellum, and in which even the sensory ganglia and the organs of special sense have only a rudimentary existence; and in which, too, the spinal cord is composed of a series of ganglia that are obviously distinct from each other, although in close approximation. And even in the lower Cyclostome Fishes, the condition of the nervous centres is very little above this, save as regards the larger development of the sensory ganglia.—This condition has its parallel, even in the Human species, in the case of Infants which are occasionally born without either Cerebrum or Cerebellum; such have existed for several hours, or even days, breathing, sucking, crying, and performing various other movements; and there is no physiological reason why their lives should not be prolonged, if they be nurtured with sufficient care.

437. In Man, however, as in all the higher Vertebrata, we find superimposed (as it were) upon the Sensory ganglia, and constituting the principal mass of the Encephalon, the bodies which are known as the *Cerebral Hemispheres*, or *Hemispheric Ganglia*. Now when these are so greatly developed as to cover-in and obscure the Sensory ganglia to the degree which presents itself in Man, it is not surprising that the fundamental importance of the latter should not be generally recognized; in Fishes, however, the proportion between the two sets of centres is entirely reversed, the rudiments of the Cerebral Hemispheres (Fig. 91, B) being usually inferior in size to the Optic ganglia (C) alone. Indeed, of the pair of ganglionic masses to which that designation is usually applied, it may be almost positively stated, that the greater part is homologous with the Corpora Striata of the Human brain; it being only in the higher Cartilaginous fishes, that a ventricular cavity exists in each of these bodies, separating the thin layer of true Cerebral substance which overlies it, from the ganglionic mass which forms its floor. Between these two extremes, a regular gradation is presented in the intermediate tribes.—Now it is a point especially worthy of note, that no sensory nerves terminate directly in the Cerebrum, nor do any motor nerves issue from it; and there seems a strong probability that there is *not* (as formerly supposed) a direct continuity between all or even any of

FIG 91.



Brain of *Cod*:—A, olfactive ganglia; B, cerebral lobes; C, optic ganglia; D, cerebellum.

the nerve-fibres distributed to the body, and the medullary substance of the Cerebrum. For whilst the nerves of 'special' sense have their own ganglionic centres, it cannot be shown that the nervous fibres of 'general' sense, which either enter the cranium as part of the cephalic nerves, or which pass-up from the Spinal cord, have any higher destination than the Thalami Optici. So the motor fibres which pass-forth from the cranium, either into the cephalic nerve-trunks, or into the motor columns of the Spinal cord, though commonly designated as *Cerebral*, cannot be certainly said to have a higher origin than the Corpora Striata. And we shall find strong physiological as well as anatomical ground for the belief, that the Cerebrum has no communication with the external world, otherwise than by its connection with the Sensori-motor apparatus; and that even the movements which are usually designated as 'voluntary' are only so as regards their original source, the stimulus which calls the muscles into contraction being even then immediately issued from the Cranio-Spinal axis, as it is in the movements prompted by the reflex stimulation of an external impression.

438. Wherever a Cerebrum is superimposed upon the Sensory Ganglia, we find another ganglionic mass, the *Cerebellum*, superimposed upon the Medulla Oblongata. The development of this organ bears a general, but by no means a constant relation to that of the Cerebrum: for in the lowest Fishes it is a thin lamina of nervous matter on the median line, only partially covering-in the 'fourth ventricle;' whilst in the higher Mammalia, as in Man, it is a mass of considerable size, having two lateral lobes or hemispheres in addition to its central portion. The direct communication which the Cerebellum has with both columns of the Spinal cord, and the comparatively slight commissural connection which it possesses with the higher portions of the Encephalic centres, justify the supposition that it is rather concerned in the regulation and co-ordination of the actions of the former, than in any proper psychical operations; and it will hereafter be shown that the various kinds of evidence afforded by Comparative Anatomy, by Experimental inquiry, and by Pathological observation, all tend to support this view of its function.

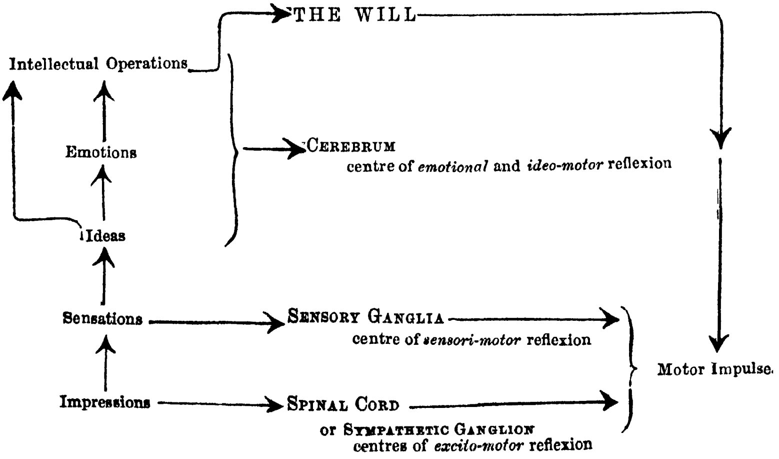
439. Now although every segment of the Spinal Cord, and every one of the Sensory Ganglia, may be considered, in common with the Cerebrum, as a true and independent centre of nervous power, yet this independence is only manifested when these organs are separated from each other; either structurally—by actual division; or functionally—by the suspension of the activity of other parts. In their state of perfect integrity and complete functional activity, they are all (at least in Man) in such subordination to the Cerebrum, that they only minister to *its* actions, except in so far as they are subservient to the maintenance of the Organic functions, as in the automatic acts of breathing and swallowing. With regard to every other action, the Will, if it possess its due predominance, can exercise a determining power; keeping in check every automatic impulse, and repressing the promptings of emotional excitement. And this seems to result from the peculiar arrangement of the nervous apparatus; which causes the excitor *impression* to travel in the *upward* direction, if it meet with no interruption, until it reaches the Cerebrum, without exciting any reflex movements in its course. When it arrives at the Sensorium, it makes an impression on the consciousness of the individual, and thus gives rise to a *sensation;* and the change

thus induced, being further propagated from the sensory ganglia to the Cerebrum, becomes the occasion of the formation of an *idea*. If with this idea any pleasurable or painful feeling should be associated, it assumes the character of an *emotion;* and either as a simple or as an emotional idea, it becomes the subject of *intellectual operations,* whose final issue is in a *volitional determination,* or act of the Will, which may be exerted in producing or checking a muscular movement, or in controlling or directing the current of thought.

440. But if this ordinary upward course be anywhere interrupted, the impression will then exert its power in a *transverse* direction, and a 'reflex' action will be the result; the nature of this being dependent upon the part of the Cerebro-Spinal axis, at which its ascent had been checked. Thus if the interruption be produced by division or injury of the Spinal Cord, so that its lower part is cut-off from communication with the encephalic centres, this portion then acts as an independent centre; and impressions made upon it through the afferent nerves proceeding to it from the lower extremities, excite violent reflex movements, which, being thus produced without sensation, are designated as 'excito-motor.'—So, again, if the impression should be conveyed to the Sensorium, but should be prevented by the removal of the Cerebrum, or by its state of functional inaction, or by the direction of its activity into some other channel, from calling-forth ideas through the instrumentality of the latter, it may react upon the motor apparatus by the 'reflex' power of the Sensory ganglia themselves; as seems to be the case with regard to those locomotive actions which are maintained and guided by sensations during states of profound abstraction, when the attention of the individual is so completely concentrated upon his own train of thought, that he does not *perceive* external objects, although his movements are obviously guided through the visual and tactile senses. Such actions, being dependent upon the prompting of sensations, are 'sensori-motor' or 'consensual.'—But further, even the Cerebrum responds automatically to impressions fitted to excite it to 'reflex' action, when from any cause the Will is in abeyance, and its power cannot be exerted either over the muscular system or over the direction of the thoughts. Thus in the states of Reverie, Dreaming, Somnambulism, &c., whether spontaneous or artificially induced, *ideas* which take possession of the mind, and from which it cannot free itself, may excite respondent movements; and this may happen also when the force of the Idea is morbidly exaggerated, and the Will is not suspended, but merely weakened, as in many forms of Insanity.

441. The general views here put-forth in regard to the independent and connected actions of the several primary divisions of the Cerebro-Spinal apparatus, may perhaps be rendered more intelligible by the following Table, which is intended to represent the ordinary course of operation when the whole is in a state of complete functional activity, and the character of the 'reflex' actions to which each part is subservient, when it is the highest centre that the impression can reach. The directing power of the Will seems to be most strongly exerted over those actions which are most closely connected with *psychical* changes, and which are exclusively *Cerebral* in their seat. It has been already pointed-out, that the Cranio-Spinal axis not merely serves as the channel for the reception of the impressions which excite the

activity of the Hemispheric ganglia, and as the instrument whereby the results of their operation are brought to bear upon the muscular system; but that it is also the centre of reflexion through which various automatic movements are called-forth, that are immediately concerned in the maintenance of the organic functions. The impressions which excite these movements do not in general pass-on to the Cerebrum; for we only perceive them when we specially direct our attention to them, or when they exist in unusual potency. Thus we are unconscious of the 'besoin de respirer' by which our ordinary movements of respiration are prompted; and it is only when we have refrained from breathing for a few seconds, that we experience a sensation of uneasiness which impels us to make forcible efforts for its relief. Notwithstanding, however, that the Cerebrum is thus unconcerned in the ordinary performance of these automatic movements, yet it can exert a certain degree of control over many of them, so as even to suspend them for a time, though in no instance can it carry this suspension to such an extent as seriously to disarrange the Organic functions; thus, when we have voluntarily refrained from breathing for a few seconds, the inspiratory impulse so rapidly increases in strength with the continuance of the suspension, that it at last overcomes the most powerful effort we can make for the repression of the movements to which it prompts (§ 276, *note*). Now in this and similar cases, it would seem as if the Will interfered to prevent that direct transverse passage of the stimulus from the afferent to the efferent nerves, through the Cranio-Spinal axis, which constitutes the ordinary line of action for impressions having their origin in the necessities of the Organic or Vegetative life of the individual. That the Will should have a certain degree of control over these movements, is necessary in order that they may be rendered subservient to various actions which are necessary for the due exercise of Man's psychical powers; but that they should not be left dependent upon its exercise, and should even be executed in opposition to it when the wants of the system imperatively demand their performance, constitutes a wise provision for securing Life against the chance of inattention or momentary caprice.



442. The Cerebro-Spinal system is intimately blended with another set of ganglionic centres and nerve-trunks, scattered in different parts of the body, but mutually connected with each other; this is commonly termed the *Sympathetic* system; but not unfrequently, from the position of its principal centres, and their evident functional relation to the apparatus of Organic life, the *Visceral* system. To this system we are probably to refer, not only the Semilunar and Cardiac ganglia (which seem to be its principal centres), with the chain of cranial, cervical, thoracic, lumbar, and sacral ganglia, which are in nearer connection with the Cerebro-spinal system; but also numerous minute ganglia, which are to be found on its branches in various parts. Moreover, the ganglia upon the posterior roots of the Spinal nerves, and those upon the roots and trunks of certain Cranial nerves, may be ranked with considerable probability under the same category; and if such be the case, those fibres contained in the Cerebro-spinal nerves, which have these as their ganglionic centres, must also be accounted as belonging to the Sympathetic system. On the other hand, there unquestionably exist numerous fibres in the Visceral system, which proceed into it from the Cerebro-spinal system; these, however, are not uniformly distributed, for some of the Visceral nerves contain few or none of them, whilst in others they are numerous. The branches by which the Sympathetic system communicates with the Cerebro-spinal, and which were formerly considered as the *roots* of the Sympathetic system, seem to contain fibres of both kinds;—*i.e.*, Cerebro-spinal fibres passing into the Sympathetic, and Sympathetic fibres passing into the Cerebro-spinal. The latter are chiefly, if not entirely, transmitted into the *anterior* branches of the Spinal nerves; the *posterior* branches being apparently supplied with sympathetic fibres from the ganglia on their own posterior roots. Some of these last fibres also pass from the Cerebro-spinal into the Sympathetic system. By these communications, the two systems of fibres are so blended with each other, that it is impossible to isolate them.—The branches proceeding from the Semilunar ganglia are distributed upon the vessels of the abdominal viscera; and those of the Cardiac ganglia upon the heart and the vessels proceeding from it. The latter seem to accompany the arterial trunks through their whole course, ramifying minutely upon their surface; and it can scarcely be doubted that they exercise an important influence over their functions. What the nature of that influence may be, however, will be a subject for future inquiry (CHAP. XV.). It is so evidently connected with the operations of nutrition, secretion, &c., that the designation 'nervous system of organic life,' as applied to this system, does not seem objectionable, provided that we do not understand it as denoting the *dependence* of these functions upon it.—The inter-penetration of the Cerebro-spinal system by the Sympathetic is strongly marked by these two circumstances;—that, in some of the lower Vertebrata, the distribution of their trunks cannot be separately distinguished;—and that, even in the highest, some of the Glands, of which the secretion is most directly influenced by the condition of the mind, are supplied with most of their nerves from the cerebro-spinal system, the lachrymal and sublingual glands receiving large branches from the fifth pair, and the mammary glands from the intercostal nerves.

443. *Cerebro-Spinal Nerve-Trunks.*—Having thus considered the principal attributes of the ganglionic centres of the Cerebro-Spinal system, we have next to inquire into those of the nerve-trunks which are connected with them. It is only in the Vertebrata, that the difference between the *afferent* and *efferent* fibres of the nerves has been satisfactorily determined. The merit of this discovery is almost entirely due to Sir C. Bell, who was led to it by a chain of reasoning of a highly philosophical character; and although his first experiments on the Spinal nerves were not satisfactory, he virtually determined the respective functions of their two roots,—the posterior as *sensory* (afferent), the anterior as *motor* (efferent),—by experiments and by pathological observations upon the Cranial nerves, some of which contain only one class of fibres to the exclusion of the other, before any other physiologist came into the field.* Subsequently his general views were confirmed by the very decided experiments of Muller; but until very recently, some obscurity hung over a portion of the phenomena. It was from the first maintained by Magendie, and has been subsequently asserted by other physiologists, that the posterior and anterior roots of the nerves were *both* concerned in the reception of impressions and in the production of motions; for that, on touching the posterior roots, not only the sensibility of the animal seemed to be affected, but muscular motions were excited: and that, when the anterior roots were touched, the animal gave signs of pain, at the same time that convulsive movements were performed. These physiologists were not willing, therefore, to admit more than that the posterior roots were *especially* sensory, and the anterior *especially* motor. But the knowledge we now possess of the 'reflex' function of the Spinal Cord enables the former portion of these phenomena to be easily explained. The motions excited by irritating the posterior roots are found to be entirely dependent upon their connection with the Spinal Cord, and upon the integrity of the anterior roots and of the trunks into which they enter; whilst they are not checked by the separation of the posterior roots from the peripheral portion of the trunk: it is evident, therefore, that excitation of the posterior roots does not act immediately upon the muscles, through the trunk of the nerve which they contribute to form; but that it excites a reflex motor impulse in the Spinal Cord, which is propagated through the anterior roots to the periphery of the system.—The converse phenomenon of the apparent sensibility of the anterior roots of the Spinal Nerves has been recently investigated and satisfactorily explained by M. Brown-Séquard. If these roots be irritated, the animal usually gives signs of uneasiness; but if they be divided, and the cut ends nearest the centre be irritated, none such are exhibited: whilst they are still shown when the farther ends are irritated, but not if the posterior roots are divided. According to M. Brown-Séquard,† these phenomena are simply due to the circumstance, that on irritating the distal extremities of the anterior roots the muscles supplied by them are thrown into a state of cramp, and pain is experienced from the violent compression ot the extremities of the sensory nerves, which of course is no longer felt when the roots of the latter are divided.

444. Every fibre, there is reason to believe, runs a distinct course,

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* See "Brit. and Foreign Med. Review," vol. ix. p. 140, &c.

† "Lectures on the Physiology of the Central Nervous System," 1860; Lecture i.

between the central organ, in which it loses itself at one extremity, and the organ of sense, muscle, or other tissue, in which it terminates at the other; in the terminal ramifications of the nerves, however, a *subdivision* of the fibres is frequently observable. Each nervous trunk is made-up of several fasciculi of these fibres; and each fasciculus is composed of a large number of the ultimate fibres themselves. Although the fasciculi occasionally intermix and exchange fibres with one another (as occurs in a *plexus*), the fibres themselves never inosculate. Each fibre would seem, therefore, to have its appropriate office, which it cannot share with another.—Several objects appear to be attained by the plexiform arrangement. In some instances it serves to intermix fibres, which have endowments fundamentally different: for example, the Spinal Accessory nerve, at its origin, appears to be exclusively motor, and the roots of the Pneumogastric to be exclusively afferent; but by the early admixture of these, a large number of motor fibres are imparted to the Pneumogastric, and are distributed in variable proportion, with its different branches; whilst a few of its sensory filaments seem to enter the Spinal Accessory.—In other instances, the object of a plexus appears to be, to give a more advantageous distribution to fibres, which all possess corresponding endowments. Thus the Brachial plexus mixes-together the fibres arising from five segments of the spinal cord, and sends-off five principal trunks to supply the arm. Now if each of these trunks had arisen by itself, from a distinct segment of the spinal cord, so that the parts on which it is distributed had only a single connection with the nervous centres, they would have been much more liable to paralysis than at present. By means of the plexus, every part is supplied with fibres arising from each segment of the spinal cord; and the functions of the whole must therefore be suspended, before complete paralysis of any part can occur from a cause which operates above the plexus. Such a view is borne-out by direct experiment; for it has been ascertained by Panizza that, in Frogs, whose Crural plexus is much less complicated than that of Mammalia, section of the roots of one of the three nerves which enter into it, produces little effect on the general movements of the limb; and that, even when two are divided, there is no paralysis of any of its actions, all being weakened in a nearly similar degree.—But as Dr. Gull has pointed out,* one use of such a plexus as the brachial or the crural appears to be, to bring the muscles which derive their nervous supply from it, into relation with different ganglionic segments of the Spinal Cord; each of which may exert a diverse action, either in virtue of its own endowments, or of the influence of the Will upon it; so that groups of muscles may thus be associated for combined actions. All consideration of the mode in which we make use of our muscles, and of the power which we have over them, leads to the conclusion that each ganglionic centre has a specific and limited sphere of influence, producing certain movements and no others; hence, for the execution of a variety of movements in harmonious combination with each other, it seems requisite that the nervous supply of each muscle should be derived from several different centres; and thus it is, that the complication of plexuses comes to be related to the variety of movements of the parts supplied through them.

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* 'Gulstonian Lectures on the Nervous System,' in "Medical Times," 1849, p. 372.

It is not a little interesting to remark, that arrangements of a similar kind present themselves among the higher Invertebrata.

445. The following statements, in which the doctrines of Prof. Müller* are adopted with some modifications and additions, embody the general principles ascertained by experiment, respecting the transmission of Sensory and Motor impressions along the nerves which respectively minister to them. Their *rationale* will be at once understood, from the facts already mentioned in regard to the isolated character of each fibril, and the identity of its endowments through its whole course.

I. When the whole trunk of a *sensory* nerve is irritated, a sensation is produced, which is referred by the mind to the parts to which its branches are ultimately distributed; and if only part of the trunk be irritated, the sensation will be referred to those parts only which are supplied by the fibrils it contains.—This is evidently caused by the production of a change in the sensorium, corresponding with that which would have been transmitted from the peripheral organs of the nerves, had the impression been made upon them. Such a change only requires the integrity of the afferent trunk between the point irritated and the sensorium, and is not at all dependent upon the state of the peripheral part to which the sensations are referred; for this may have been paralysed by the division or other lesion of the nerve, or may have been altogether separated as in amputation, or the relative position of its parts may have been changed, as in autoplastic operations. So, when different parts of the thickness of the same trunk are separately and successively irritated, the sensations are successively referred to the several parts supplied by these divisions. This may be easily shown by compressing the ulnar nerve in different directions, where it passes at the inner side of the elbow-joint.—Still the mind undoubtedly does possess a certain power of discriminating the part of the nerve-trunk on which the impression is made; for whilst this impression is such as to produce sensations that are referred to its peripheral extremities, pain is at the same time felt in the spot itself; and it would seem as if slight impressions are *only* felt in the latter situation, at least in the normal condition of the trunk or fibre. Thus, as it has been well remarked by Volkmann, "if a needle's point be drawn in a straight line across the back, or the thigh, or any part in which the nerves are widely placed, the mind perceives the line of irritation as a straight one; whereas, if it referred all impressions to the ends of irritated fibres. this mode of irritation should be felt in sensations variously scattered about the line, at the points where the nerve-fibres crossed by the needle terminate."†

II. The sensation produced by irritation of a branch of the nerve is confined to the parts to which that branch is distributed, and does not affect the branches which come-off from the nerve higher up.—The rationale of this law is at once intelligible: but it should be mentioned that there are certain conditions, in which the irritation of a single nerve will give rise to sensations over a great extent of the body. This

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* "Elements of Physiology," translated by Dr. Baly; pp. 680, 686.

† Kirkes and Paget's "Handbook of Physiology," p. 375.—It does not seem improbable, however, that in the case of the compression or other irritation of a large nerve-trunk, the *local* pain may be produced through the instrumentality of *nervi nervorum*, the existence of which is scarcely less probable than that of *vasa vasorum*.

'radiation of sensations' seems rather due, however, to a particular state of the *central* organs, than to any direct communication among the peripheral fibres.

III. The *motor* influence is propagated only in a centrifugal direction, never in a retrograde course. It may originate in a spontaneous change in the central organs, or it may be excited by an impression conveyed to them through afferent nerves; but in both cases its law is the same.

IV. When the whole trunk of a motor nerve is irritated, all the muscles which it supplies are caused to contract. This contraction evidently results from the similarity between the effect of an artificial stimulus applied to the trunk in its course, and that of the change in the central organs by which the motor influence is ordinarily propagated. But when only a part of the trunk or a branch is irritated, the contraction is usually confined to the muscles which receive their nervous fibres from it; in this instance, as in the other, there is no lateral communication between the fibrils.—An exception exists, however, in regard to galvanic irritation, which may be transmitted laterally when its ordinary course is checked; as has been shown by the following ingenious experiment of M. du Bois-Reymond. If any motor nerve be selected which divaricates into two branches (as, for example, the sciatic nerve of a frog, which divides above the bend of the knee into the tibial and peroneal branches), and a galvanic stimulus be applied to either of these branches, this having been first divided above its insertion into the muscles, the electrotonic state will be developed, not merely in the portion of the trunk continuous with that branch, but also in that which is continuous with the other branch, as will be made apparent by the contraction in the muscles supplied by the latter. That this experiment may be free from the possible fallacy resulting from the excitement of reflex action, the trunk of the sciatic nerve should be divided high-up, or the spinal cord be destroyed.

446. *Determination of the Functions of Nerves.*—Various methods of determining the functions of particular nerves present themselves to the Physiological inquirer. One source of evidence is drawn from their *peripheral distribution.* For example, if a nervous trunk is found to lose itself entirely in the substance of Muscles, it may be inferred to be chiefly, if not entirely, *motor* or *efferent.* In this manner Willis long ago determined that the Third, Fourth, Sixth, Portio Dura of the Seventh (or Facial), and Ninth cranial nerves, are almost entirely subservient to muscular movement; and the same had been observed of the fibres proceeding from the small root of the Fifth pair, before Sir C. Bell experimentally determined the double function of that division of the nerve into which alone it enters. Again, where a nerve passes through the muscles, with little or no ramification among them, and proceeds to a Cutaneous or Mucous surface on which its branches are minutely distributed, there is equal reason to believe that it is of a *sensory* or rather of an *afferent* character. In this manner Willis came to the conclusion, that the Fifth pair of cranial nerves differs from those previously mentioned, in being partly sensory. Further, where a nerve is *entirely* distributed upon a surface adapted to receive impressions of a *special* kind, as the Schneiderian membrane, the retina, or the membrane lining the internal ear, it may be inferred that it is not capable of transmitting any

other kind of impressions; for experiment has shown that the *special sensory* nerves do not possess common sensibility. The case is different, however, in regard to the sense of taste, which originates in impressions not far removed from those of ordinary touch; and it is probable that the same nerves minister to both.—Anatomical evidence of this kind is valuable also, not only in reference to the functions of a principal trunk, but even as to those of its several branches, which, in some instances, differ considerably. Thus, some of the branches of the Pneumogastric are especially motor, and others almost exclusively afferent; and anatomical examination, carefully prosecuted, not only assigns the reasons for these functions, when ascertained, but is in itself nearly sufficient to determine them. For the superior laryngeal branch is distributed almost entirely upon the mucous surface of the larynx, the only muscle it supplies being the crico-thyroid; whilst the inferior laryngeal or recurrent is almost exclusively distributed to the muscles. From this we might infer, that the former is an afferent, and the latter a motor nerve; and experimental inquiries (as we have seen, § 281) fully confirm this view. In like manner it may be shown, that the Glosso-pharyngeal is chiefly an afferent nerve, since it is distributed to the *surface* of the tongue and pharynx, and scarcely at all to the muscles of those parts; whilst the pharyngeal branches of the Pneumogastric are chiefly, if not entirely, motor (§ 69). Lower down, however, the branches of the Glosso-pharyngeal cease, and the œsophageal branches of the Pneumogastric are distributed both to the mucous surface and to the muscles, from which it may be inferred that they are both afferent and motor; a deduction which experiment confirms (§ 70).—We perceive, therefore, that much knowledge of the function of a nerve may be obtained from the attentive study of its ultimate distribution; but it is necessary that this should be very carefully ascertained, before it is made to serve as the foundation for physiological inferences. As an example of former errors in this respect, may be mentioned the description of the Portio dura of the Seventh (or Facial) at first given by Sir C. Bell; for he incorrectly stated it to be distributed to the skin as well as to the muscles of the face, and erroneously regarded it as in part an afferent nerve, subservient to respiratory impressions as well as to motions. In the same manner, from inaccurate observation of the ultimate distribution of the Superior Laryngeal nerve, it was long regarded as that which stimulated to action the constrictors of the glottis.

447. But the knowledge obtained by such anatomical examinations alone is of a very general kind; and requires to be made particular,—to be corrected and modified,—by other sources of information. One of these relates to the *connection of the trunks with the central organs.* The evidence derived from this source, however, is seldom of a very definite character; and, in fact, Physiologists have rather been accustomed to judge of the functions of particular divisions of the nervous centres by those of the nerves with which they are connected, than to draw aid from the former in the determination of the latter. Still, this kind of examination is not without its use, when there is reason to believe that a particular tract of fibrous structure has a certain function, and when the office of a nerve whose roots terminate in it is doubtful. Here, again, however, very minute and accurate examination is necessary, before any

sound physiological inferences can be drawn from facts of this description; and many instances might be adduced to show, that the real connections of nerves and nervous centres are often very different from their apparent ones.

448. Most important information as to the functions of particular nerves may be drawn from *experimental inquiries;* but these also are liable to give fallacious results, unless they are prosecuted with a full knowledge of all the precautions necessary to insure success. Some of these will be here explained.—In the first place, the endowments of the *trunk* and of the *roots* of a nerve may differ; owing to the admixture, in the former, of fibres derived by inosculation from another nerve (§ 444). Hence, in order to attain satisfactory results, a comparative set of experiments should always be made upon each.—A nerve-trunk may be too hastily considered as *motor*, on account of the excitation of muscular movements by irritation of its trunk, whilst still in connection with its centre; for such movements may be called-forth, not only by the direct influence of the nerve upon the muscles, but also by reflex stimulation acting through the ganglionic centre upon some other nerve. The real nature of such movements can only be determined by dividing the trunk, and then irritating each of the cut extremities. If, upon irritating the end *separated* from the centre, muscular contractions are produced, it may be safely inferred that the nerve is, in part at least, of an *efferent* character. Should no such result follow, this would be improbable. If, on the other hand, muscular movement should be produced by irritating the extremity *in connection with* the centre, it will then be evident, that it is occasioned by an impression conveyed *towards* the centre by *this* trunk, and propagated to the muscles by some other; in other words, to use the language of Dr. M. Hall, this nerve is an 'excitor' of motion, not a direct motor nerve. The Glosso-pharyngeal has been satisfactorily determined, by experiments of this kind, performed by Dr. J. Reid (§ 69), to be chiefly, if not entirely, an afferent nerve.—It has been from the want of a proper mode of experimenting, that the functions of the *posterior* roots of the Spinal nerves have been regarded as in any degree motor. If they be irritated, without division of either root, motions are often excited; but if they be divided, and their separated trunks be then irritated, no motions ensue; nor are any movements produced by irritation of the roots in connection with the spinal cord, if the *anterior* roots have been divided. Hence it appears that these fibres do not possess any direct motor powers, but that they convey impressions to the centre, which are reflected to the muscles through the anterior roots.—The same difficulties do not attend the determination of the *sensory* endowments of nerves. If, when the trunk of a nerve is pricked or pinched, the animal exhibits signs of pain, it may be concluded that the nerve is capable of receiving and transmitting sensory impressions from its peripheral extremity. But it not unfrequently happens that this capability is derived by inosculation with another nerve; as is the case with the Facial, which is sensory after it has passed through the parotid gland, having received there a twig from the Fifth pair.

449. The fallacies to which all experiments upon the nerves are subject, arising from the partial loss of their power of receiving and conveying impressions, and of exciting the muscles to action, after death, are too

obvious to require more particular mention here; yet they are frequently overlooked. Of a similar description are those arising from severe disturbance of the system, in consequence of operations; which also have not been enough regarded by experimenters.—As a general rule, *negative* results are of less value than *positive;* but very careful discrimination is often required to determine what *are* negative, and what positive results. Each particular case has its own sources of fallacy, which require to be logically scrutinized; and the only satisfactory proof is derived from the concurrence of every kind of evidence which the nature of the inquiry admits-of. Thus in the determination of the functions of a particular nerve-trunk, it should be shown that a certain effect is *constantly* produced by its excitation (under the conditions laid-down in the preceding paragraph), and that a corresponding interruption in the action to which it is hence inferred to be subservient, takes place when its continuity has been interrupted: by this double proof, the Glosso-pharyngeal and the Pneumogastric are shown to be the principal, but not the sole, excitors of the movements of Deglutition and Inspiration respectively. But the evidence afforded solely by the interruption of a particular function, after the division of a certain nerve, or the destruction or removal of a nervous centre, is by no means so satisfactory; for this may be occasioned rather by the general effects of the operation, than by the simple lesion of the nervous apparatus. In order to get rid, so far as possible, of this source of fallacy (which particularly affects experiments upon the Encephalic centres, and upon the influence of the nerves upon the viscera), it is desirable to perform comparative experiments, in which the general injury shall be as nearly as possible the same, and the only difference shall lie in the lesion of the nervous system; and to subtract from the entire result all that can be thus shown to be attributable to the general disturbance produced by the operation. But even then, it may happen that the function is only suspended for a time, by the shock which has been induced by the injury to the nerve; and if it should be subsequently renewed without any reunion of the trunk, we have the most convincing proof that, whatever degree of participation the nerve may have in it, the action is not essentially dependent upon the integrity of that portion of the nervous apparatus. Such we have seen to be the case, in regard to the relation of the Pneumogastric nerves to the secretion of gastric fluid in the walls of the stomach (§§ 88, 89).

450. All our positive knowledge of the functions of the Nervous System in general, save that which results from our own consciousness of what passes within ourselves, and that which we obtain from watching the manifestations of disease in Man, is derived from observation of the phenomena exhibited by animals made the subjects of experiments; and in the interpretation of these, great caution must be exercised.—In the first place it must be constantly borne in mind, that, except through the *movements* consequent upon them, we have no means of ascertaining, whether or not particular changes in the Nervous System, whose character we are endeavouring to determine, are attended with Sensation; since we have no power of judging whether or not this has been excited, save by the cries and struggles of the animal made the subject of experiment. Now although such cries and struggles are ordinarily considered as indications of pain, yet it is not right so to regard them in every instance; and the

only unequivocal evidence is derived from observation of the corresponding phenomena in the Human subject; since we can there ascertain, by the direct testimony of the individual affected, what impressions produce sensation, and what excite movements independently of sensation. Further, we are not justified in assuming that Consciousness is excited by an irritation, still less that Intelligence and Will are called into exercise by it, merely because movements evidently tending to get rid of its source are performed in respondence to it. We know that the contractions of the heart and alimentary tube are ordinarily excited by a stimulus, without any sensation being involved; and these movements, like all that are concerned in the maintenance of the Organic functions, have an obvious *design*, when considered either in their immediate effects, or in their more remote consequences. The character of *adaptiveness*, then, in Muscular movements excited by external stimuli, is no proof that they are performed in obedience to sensation; much less that they have a voluntary character. In no case is this adaptiveness more remarkable, than in some of those actions, which are not only performed without any effort of the will, but which the will cannot imitate. This is the case, for example, with the act of Deglutition (§§ 66, 67), the muscles concerned in which cannot be thrown into contraction by a voluntary impulse, being stimulated only by impressions conveyed from the mucous surface of the fauces to the Medulla Oblongata, and thence reflected along the motor nerves. No one can swallow, without producing an impression of some kind upon this surface, to which the muscular movements will immediately respond. Now it is impossible to conceive any movements more perfectly adapted to a given purpose, than are those of the parts in question; and yet they are independent, not only of volition but of sensation, being still performed in cases in which consciousness is completely suspended or entirely absent. The act of Sucking in the infant, again, is one in which a number of muscles are called into combined contraction, in a manner which shows a complete adaptation to a given purpose; and yet it is impossible to suppose this adaptation to be *purposive* on the part of the infant itself; more especially as it is shown, both by the occurrence of monstrosities, and by experiments made with this object, that no part of the Cranio-spinal axis above the Medulla Oblongata is necessary to it. And in the acts of Coughing and Sneezing (§ 280), we have additional examples of the most *adaptive* movements, executed by a marvellous combination of separate muscular actions, with the obvious purpose of removing sources of irritation from the air-passages; and yet we know by personal experience, that this combination is *not* made with any design of our own.

451. The activity of the nervous ganglia and of the nervous cords is alike called into action by the application of stimuli. These vary in their nature, and whilst some, as electrical currents, chemical agents and mechanical pressure, can excite all nerves to action, others, like the vibrations of light and sound, odorous emanations, and heat, appear to be only capable of exciting nerves whose intimate structure especially adapts them for responding to the impressions made by these delicate yet active agents. It is probable that in all instances the condition of nervous activity is accompanied by a change in the molecular condition of the particles of the nerve, which is more easily effected in sensory than in

motor nerves, the latter requiring a much more energetic operation of the several kinds of stimuli than the former. Whatever may be the nature of the stimulus acting upon a nerve, and however energetic its operation, neither sensation nor motion is produced when the passage from one grade of intensity to another is extremely gentle. Thus, if mechanical pressure be so applied to a motor nerve, as that, commencing with the slightest possible contact, it may steadily and continuously increase in force even till the nerve be killed at that spot, no convulsions occur in the muscles to which it is distributed.* Muscular contraction only supervenes when sudden changes, producing a kind of shock, are made either in increasing or diminishing pressure. In proportion to the energy of the shock or vibration of the particles of the nerve, is the effect produced on the muscles: thus we see that tetanic convulsions may be induced by violent extension of a nerve, and that the whole body of a decapitated frog can be rendered rigid by throwing it on the ground. In a similar manner, whilst the sudden application of a ligature to a sensory nerve produces acute pain, numbness ultimately passing into entire insensibility is the only effect if it be gradually applied. Chauveau† has endeavoured to explain the effects of even the electrical current on the supposition that it produces a mechanical commotion in the particles of the nerve. Chemical stimuli act but slowly on nerves, which we may attribute to the sheath of the fibres affording a certain amount of protection to the contents. The sensory nerves appear to be much more readily acted on, and by a much greater range of chemical agents, than the motor nerves; powerful stimuli for the latter are, however, found in solutions of Soda and Potash, even when not exceeding 2 per cent, in those of Nitrate of Potash and of Hydrochloric acid, containing 20 per cent, and in concentrated solutions of Ammonia and Alcohol (90 per cent); the latter, however, rapidly killing the nerve at the point where they have been applied. Bisulphide of carbon, the ætherial oils, and concentrated mineral acids, kill the nerve at once without producing convulsions.‡ Water applied to nerve-trunks excites no muscular contractions, but if injected into the vessels distributed to a muscle induces very violent convulsions, which are believed by Schiff to be due to the direct effect of the water upon the delicate terminations of the nerves in the muscles. Withdrawal of water from the nerves, if effected gradually, produces no effect, but if accomplished rapidly, produces tetanus.§ As regards thermic irritation as a stimulus for the nerves, it has been shown by Weber that the sensory nerves do not perceive positive temperature, but only variations in the degree of heat of external objects. The influence of variations of temperature on motor nerves has been investigated by Eckhard, who has shown that a temperature of about 130° F. produces convulsions in frogs, which, however, soon cease; the irritability of the nerves being then lost, though upon cooling they occasionally regain it. Sudden exposure to a temperature of about 25° F. also produces convulsions.‖ Temperatures intermediate to these limits do not occasion convulsions, but the nerve soon loses its irritability when exposed to those near either the higher or the lower extreme. Moreover, here also sudden variations produce convulsion with more certainty than when the change is slow and gradual.

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* Schiff, "Physiologie," 1859, p. 94.

† Chauveau, Brown-Séquard, "Journ. de la Physiologie," 1859, p. 576.

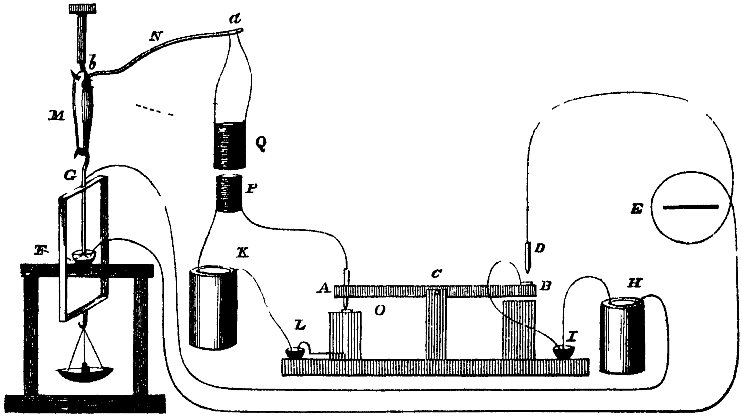
‡ Schiff, "Physiologie," 1859, p. 101.

§ Harless, "Zeitschrift f. Rat. Med.," band vii. p. 219.

‖ Eckhard, "Zeitschrift f. Rat. Med.," band x. p. 165; and Harless, ditto, band viii. p. 122.

452. The rapidity with which sensory and motor impressions are transmitted through the Nerves of the living body is apparently so great, and the means of estimating it at our disposal so few, that it is doubtful whether we shall ever be able to determine it with accuracy; but the ingenuity of Helmholtz has enabled him to ascertain with some precision the rate at which the change induced by the passage of an electrical current is propagated along a small portion of a nerve. The following Figure and description deserve attention, since they exhibit the mode in which physical research can be applied to the most recondite questions of animal life. It is required to measure the time which any excitation takes to travel from the cut end *a* of the nerve N to its point of entrance *b* into the muscle M. As the means of excitation, Helmholtz employs an instantaneous induction current in the following mode:—At the moment that a constant current passing through the coil P, from the battery K, *is broken*, an instantaneous *induced* current passing in the same direction is excited in Q; this is the stimulus acting on the nerve at *a*. The time-measuring current is formed by a second battery H, into some part of whose circuit a galvanometer E is introduced. It is requisite that the closure of this current should be precisely coincident with the opening of the inducing current from K, by which the induced current at Q, or the stimulus, is produced; this is effected by the lever A B C, whose arm A rests on the metal plate O and completes the circuit K L A P. If now the metal point D be forcibly pressed on B, the time-measuring current passing through H I B D E F G will be closed; but at the same instant, from the depression of the arm B, the stimulus will be applied to the nerve through the opening of the inducing current K L A P, which is the result of the elevation of the arm A. But as

Fig. 92.



soon as the stimulus has reached the muscle M, after traversing the nerve N the muscle contracts, raising with it the hook G, which just dips into the cup of mercury F, and consequently breaking the time-measuring current proceeding from the battery H. The *extent* to which the galvanometer needle has been deflected indicates the time during which the current has been flowing through the circuit H I B D E F G, that is, the time which has intervened from the instant of the application of the stimulus to the nerve at *a*, to the moment when the contraction of the muscle breaks that current. A portion of this time is occupied in the transmission of the stimulus from the point *a* to the muscle, and a portion, termed the period of latent excitation, elapses before the muscle responds to the stimulus. In order to ascertain the duration of the former period, the experiment is repeated with this alteration, that the stimulus is applied at *b*, and again the extent to which the needle is deflected is read off; the difference between the two observations then gives the time occupied by the stimulus in passing from *a* to *b*. From numerous experiments with this instrument, Helmholtz arrived at the conclusion that in the Frog, at a temperature between 52° F. and 70° F., the rapidity of the propagation of impressions along motor nerves was from 81 to 126 feet per second, and he estimates the rapidity for human nerve at somewhat more than 200 feet per second. In the chronoscopic researches of M. Adolph Hirsch,[*] the rapidity of propagation of sensations along the nerves of common sensibility is estimated to be about 34 metres, or 110 feet per second. That considerable differences exist in the rapidity of propagation in the Nerves themselves is evident, as Budge[†] remarks, from the effects produced on the Iris by irritating the Third and the Fifth nerves in Rabbits, contraction following quickly in the former and slowly in the latter case. And Colin[‡] has noticed that if the sympathetic ganglia are strongly irritated, reflex movements are immediately produced; but when the excitation is more feeble, a longer time elapses before the movements occur. M. Hirsch has even attempted to determine the relative rapidity with which impressions are transmitted through the nerves of sight, hearing, and touch; and the following Table gives his conclusions, in which the term 'Physiological time' signifies the period occupied in the perception of the impression, and in the origination and execution of the muscular movement by which the time was registered:—

Sense.	Physiological Time.	Mean Variation.
1. Hearing	0·149	± 0·025
2. Visual perception of a spark	0·200	± 0·016
3. Visual perception of the transit of a star	0·077	± 0·025
4. Touch (left hand)	0·182	± 0·016

Thus it will be observed that the perception and registration of an unexpected appearance (spark) occupies much more time than the perception of a slowly-awaited one (transit observation), and one-third more than even the perception of a sound; but the mean variation in the latter case was considerably greater.

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[*] "Moleschott's Untersuch.," band ix. heft ii. 1863, p. 183.

[†] "Physiologie," p. 655, 1862.

[‡] "Comptes Rendus," 1861, i. p. 969.

453. *Electrical Currents of the Nerves.*—The discovery that an electric current exists in *Nerves*, is entirely due to M. du Bois-Reymond. When a small piece of a nerve-trunk is cut-out from the recently-killed body, and is so placed upon the electrodes of a Galvanometer that it touches one of them with its surface (or natural *longitudinal* section), and the other with its cut extremity (or artificial *transverse* section), a considerable deflection of the index is produced, the direction of which always indicates the passage of a current from the interior to the exterior of the nerve-trunk. It is indifferent in regard to the direction of the current, whether the central or the peripheral cut extremity be applied to the electrode; and in fact the most powerful effect is obtained by doubling the nerve in the middle, and applying both transverse sections to one electrode, whilst the loop is applied to the other. On the other hand, if the two cut extremities be applied to the two electrodes respectively, no decided effect is produced; and the same neutrality exists between any two points of the surface of the trunk, equidistant from the middle of its length; but if the points be not equidistant, then a slight deflection is produced, indicating that the parts nearer the middle are positive to those nearer the extremities. It has not been found possible, owing to the small size of the nerve-trunks experimented-on, to test in a similar manner the relative state of different points of their transverse section; but there can be little doubt, from the complete conformity which exists in other respects between nervous and muscular currents, that the same law will be found to prevail in the former as in the latter case; namely, that the points nearer the surface are positive to those nearer the centre. There is no difference between the motor and the sensory nerves in regard to the direction of this current, the existence of which has been proved by M. du Bois-Reymond, not only by the galvanometer, but also by the excitement of contractions in the limb of the galvanoscopic frog.—The 'nervous current,' like the muscular, must be considered as derived from the electromotive action of the molecules of the nerve; and it seems unquestionable, that every integral particle of the nervous substance must be a centre of electromotor action, and must contain within itself positive and negative elements; and the variations both of intensity and direction in the nervous current, under certain circumstances, are so sudden and so extensive, that it appears impossible to account for them by any change of larger heterogeneous elements, or in any other way than by assuming corresponding changes of position in almost infinitely small centres of action. It is indifferent what form is assigned to these electromotive molecules; but it would seem that they must have two negative polar zones, and a positive equatorial zone; a combination of such elements being able to produce all the electrical effects of a nerve in a state of rest. It seems altogether best to suit the phenomena, to suppose that each of these *peripolar* molecules is formed by the combination of two *dipolar* molecules, touching each other by their positive poles,—as in the subjoined Table, which represents a band of four series, A, B, C, D, each series containing four dipolar molecules.

	1	2	3	4
A. . . .	—++—	—++—	—++—	—++—
B. . . .	—++—	—++—	—++—	—++—
C. . . .	—++—	—++—	—++—	—++—
D. . . .	—++—	—++—	—++—	—++—

Dr. Radcliffe* thinks it is more easy to suppose that each nervous fibre is composed of two sets of electrical molecules; one set in which the positive electricity is external, and the negative electricity internal; the other set in which the negative electricity is external, and the positive electricity internal: and further, that those molecules in which the negative electricity is external are arranged in the core of the fibre, and that the molecules in which the positive electricity is external are clustered together as a coating around this core; whence it follows that "the longitudinal surface of the fibre will be electrified positively, seeing that it is composed of molecules of which the positive electricity is external, and the transverse surface would be electrified negatively, for this surface involves the exposure of molecules of which the negative electricity is external." The relative position of these sets of molecules may, however, under certain circumstances, be changed; and the very remarkable modification of the 'nervous current,' which has been shown by M. du Bois-Reymond to follow severe injuries of the nerve by mechanical, chemical, or thermal agencies, appears to be attributable to such an alteration. If, for instance, a piece of hot metal be brought near to the nerve without touching it, the nervous current will be seen to diminish rapidly, and to have its direction reversed, during which the property possessed by the nerve of conveying irritation to the muscle, though somewhat impaired, will not be destroyed; and if, whilst in this abnormal state, the nerve be divided, every transverse section is found neutral or positive to the longitudinal section, instead of negative. If the nerve-trunk be then placed between muscles, so as to recover its natural moisture, it will at the same time recover its usual electromotive power. According to M. du Bois-Reymond, the *current* shown by the entire nerve, when made to form part of a circuit, is only a *derived* current produced by incomparably more intense currents circulating in the interior of the nerve around these ultimate particles, varying greatly in intensity according to the mode in which these particles are arranged; but, generally speaking, increasing both with the length and with the thickness of the nerve. Dr. Radcliffe, however, believes that all the phenomena of sensation and motion can be better explained on the supposition that the primary electrical condition of living muscle and nerve is one of *statical*, and not one of current electricity; for by this means the various signs of electrical tension which can readily be shown in living nerve, and which is so characteristic of statical as contradistinguished from current electricity, can be rendered easily intelligible; and he consequently believes the "current" which may be shown to be present in living nerve in a state of inaction is a *secondary*, and not, as M. du Bois-Reymond considered it, a *primary* phenomenon. Putting aside Dr. Radcliffe's theory for the present, we have now to follow M. du Bois-Reymond through his investigations on the change in the condition of the 'nervous current,' whilst the nerve is in a state of functional activity, whether motor or sensory. For the examination of this, it is desirable to induce a state of continuous action in the nerve, analogous to the tetanic contraction of muscle; and this condition in the motor nerve is manifestly that which induces tetanus in its muscle, whilst in sensory nerves it is that in which a violent sensation is uninterruptedly kept-up. No means of exciting such a state are so certain and simple, as electric currents; but it is necessary in the first place to determine the modification which these currents may themselves produce in the proper 'nervous current.' If a portion of nerve-trunk be so placed (Fig. 93) that it touches one of the electrodes by its transverse section (which may be designated T), and the other by its surface or longitudinal section (L), and a portion of its continuation be included in a galvanic circuit, so that a current shall pass in the direction Z—P, which is *the same* in its direction as that between T—L, then the intensity of the 'nervous current' T—L, as indicated by the deflection of the needle of the galvanometer, will be found to undergo an increase; whilst on the other hand, if the electric current be passed in the contrary direction P—Z, the intensity of the 'nervous current' T—L will decrease.—The portion Z—P of the nerve, which is included in the electric circuit, is termed the *excited* portion, and the current passed through it is the *exciting current;* on the other hand, the portion T—L included between the electrodes of the galvanometer is the *derived* portion; and the altered condition of this part, which is produced by the extraneous current (this current having been experimentally proved by M. du Bois-Reymond to exert no influence of its own on the galvanometer), is termed the *electrotonic state* of the nerve. When the intensity of the 'nervous current' is increased, the nerve is said to be in the *positive phase* of this electrotonic state; and when it is diminished, the nerve is in the *negative phase* of that state.—By a proper arrangement, the same exciting current may be made to produce the positive phase in one part of a nerve-trunk, and the negative phase in another. Thus if the two extremities of a nerve (Fig. 94, *p* and *c*) be so connected with two galvanometers that both shall develope the 'nervous current,' and an intermediate portion be excited by the transmission of an electric current in the direction Z—P, the nervous current in the 'derived' portion *c* will be increased in intensity, whilst that in the portion *p* will be diminished.

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* "Lectures on certain Disorders of the Nervous System," 1854, p. 21.

FIG. 93.

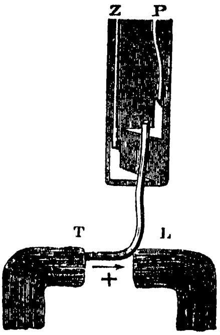
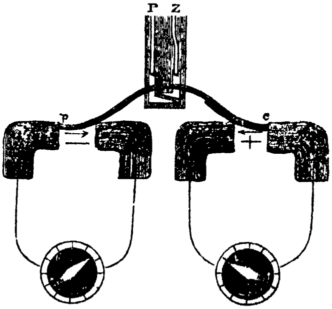


FIG. 94.



454. Hence it may be inferred, that when any portion of the length of a nerve is traversed by an electric current, besides the usual electromotive action of the nerve, a new electromotive action takes place in every point of the nerve, by a polarization of its electromotive elements,

which action has the same direction as the exciting current itself; and a current is thus produced in the 'derived' portion, which is added to the original 'nervous current' at that end of the nerve at which the direction of this new current and of the nervous current coincide (*c*), and is subtracted at that end at which the directions are different (*p*). The intensity of the electrotonic condition is found to be materially affected by the distance at which the nerve is examined from the point where the 'exciting current' is applied, being always much greater near that point than at a considerable distance from it. It is also powerfully influenced by the strength of the exciting current, and by the length of the portion of nerve through which that current passes, increasing in intensity with stronger currents, and diminishing in proportion to the length of nerve the current has to traverse. These variations in the intensity of the 'nervous current' continue as long as the 'exciting current' lasts, and immediately cease when the circuit of that current is broken. It is to the induction of the electrotonic state in the nerve supplying it, that the contraction of a muscle is due, which ensues on the completion of the circuit; and to the cessation of this state, that the muscular contraction is due which is consequent upon the interruption of the circuit. Hence the electrotonic changes in the condition of nerves may be observed without previously dividing them.—When, on the other hand, a nerve is 'tetanized' by passing an interrupted and alternating current through a portion of it, the effect is, as in the case of muscle, to produce a *diminution* in its own proper current; the needles of *both* galvanometers, in the arrangement last described, being deflected to the negative side, instead of one going back to zero and the other having its positive deflection increased, as happens when the 'excited portion' is subjected to a continuous and uniform current. The same negative variation of the nervous current has been demonstrated by M. du Bois-Reymond in nerves tetanized by other means, as by the use of strychnia. And the phenomena both of the 'electrotonic state,' and of the 'negative variation' *are precisely the same, whether motor or sensory nerves be subjected* to the experiment; thus making it appear that nerve-force may be transmitted in either direction along each of these orders of nerves.—Dr. Radcliffe has pointed out that this disappearance of the signs of current electricity in motor nerves at the moment of action, when taken into consideration with the fact particularly indicated by Matteucci, that the state of action in a motor nerve is accompanied by a discharge of electricity analogous to that of the torpedo, leads to the supposition that ordinary muscular contraction and rigor mortis may both be dependent upon the *absence* of the natural electricity which is present in living nerve and muscle during the state of inaction.

455. Although the conducting power of the Nerves for electrical currents is many thousand times less than metallic threads, electricity appears to be the stimulus which most readily affects them, whatever may be their function; exciting not only the various sensory nerves, but being also the most powerful agent with which we are acquainted for inducing the contraction of muscles when applied to the motor nerves that supply them. The effects of electricity upon nerves differ remarkably according to whether a continuous or an interrupted current is employed. A continuous current passed across a nerve at right angles occasions no

contraction; but if it be directed up or down the nerve, contraction commonly occurs at the moment of closing and opening the current, though none during its steady and uniform passage. With an interrupted current, on the contrary, the nerve being kept in a constant state of excitation, the muscles supplied by it pass into a state of permanent or tetanic contraction. With a continuous current, contraction is observed to take place, not only at the moment of closing and opening, but also when any sudden change, either of increase or decrease, occurs in the intensity of the transmitted current. These phenomena have been expressed by Du Bois-Reymond in the following proposition, which, whilst it is especially applicable to the passage of electrical currents, yet holds equally for all kinds of stimuli. He states that a motor nerve is not excited by the absolute amount of the intensity of the current, but by the variations of this amount from one instant to another; and the excitation caused by these changes is the greater the more rapidly the changes take place, or the greater they are in a given time.—There are, however, certain exceptions to this law, which indicate that it does not include all the phenomena: thus, under certain circumstances, tetanic convulsions occur in the muscle, though the current traversing the nerve may not vary in intensity; and again, it is well known that the *sensory nerves*, and especially those of *special sense*, are not excited during the moment of opening and closing the current alone, but during the whole time of its passage. These exceptions were examined by Pfluger, who found that the effects produced in the case of the motor nerves at least, depended upon the strength of the current, and that if he passed a succession of constant currents, gradually increasing in intensity, through a nerve, the weakest currents were only capable of inducing contraction on closure; but that very soon, on slightly increasing the intensity of the current, tetanus occurred, which became more and more strongly marked as the intensity of the current increased up to a certain point; but when the strength of the current exceeded this, the tetanus again disappeared, and did not recur even when the strongest currents were passed, though after a little while it might again be produced by passing weak currents through the nerve.—Pfluger's explanation of this power of inducing tetanus, possessed by weak currents, is equally applicable to that produced by chemical, thermic, or mechanical irritation. It is that "the nerve becomes excited whenever any external force changes its internal molecular constitution with a certain rapidity, whilst a static condition of the nerves is never associated with their excitation." Consequently, when tetanus occurs during the passage of a constant current through the nerve, the molecules of the nerve are not at rest, but in movement; the movement being essentially a process of electrolysis, in which the molecules or elementary particles of the nerve originally arranged as — + + —, — + + —, become changed to — + — +, — + — +, in consequence of one of each pair of molecules turning half round upon itself; without this change the passage of the current is not conceivable, and on its occurrence the tetanizing influence depends. But we may naturally ask, if this be true, why do currents of weak intensity alone produce Tetanus? and in order to reply to this question, it is necessary to anticipate, to some extent, the observations made by Eckhard and Pflüger, on the condition of the nerve during the passage of a constant current. Pflüger has ascertained, by means to be subsequently described, that when a constant current is transmitted through a portion of nerve, whatever may be the strength of the current, and whether transmitted centripetally or centrifugally, the portion of nerve traversed by the current divides, as it were, into two zones: in one of these, situated at and near the Positive pole, the excitability of the nerve is diminished; whilst in the other, situated at and near the Negative pole, the excitability is increased. The extent of the portion of nerve in which the excitability is lowered, or the Positive zone, is small in proportion to the weakness of the current; whilst the Negative zone, in which the excitability is exalted, is large in proportion to the weakness of the current; so that with very weak currents nearly the whole length of the nerve is in a state of exalted excitability, whilst with strong currents the intrapolar portion of the nerve is almost wholly lowered in excitability. Hence the tetanus which supervenes when weak currents pass through the nerves, is due to the electrolytic action induced by the current acting as a stimulus to the nerve in a state of exalted excitability; whilst strong currents produce no tetanus, although the electrolytic actions are more energetic, because they act upon the nerve when its excitability is lowered. From these considerations Pflüger suggests the following modification of the law of Du Bois-Reymond, viz., that "although the excitation of a nerve primarily depends on variations in the intensity of the current traversing it, yet the nerve constantly reacts upon the current to a certain amount; and this reaction begins to occur with weak currents, increases with increasing strength of the current, attains its maximum, and finally with very strong currents vanishes."

456. During life, and in the healthy state, the excitability of a motor nerve gradually diminishes from its origin to its distribution in the muscle, so that a stimulus of determinate intensity produces a more energetic contraction of a muscle in proportion to the distance from the muscle that it is applied to the nerve, or as it is expressed by Pflüger, in proportion to the length of the myopolar portion of nerve. Thus Budge found that to produce the same effect, *i.e.* the same amount of contraction, it was necessary to apply a stimulus of more than double the strength close to a muscle, than was requisite if the stimulus were applied to the portion of nerve near its origin. The question arises whether the nerve is itself more excitable at the parts nearer the centre, or whether the stimulus does not gain force in its descent, and produce, like an avalanche, an effect greater in proportion to the distance it has traversed. Pflüger expresses himself decisively in favour of the latter supposition. Yet it seems opposed to our ordinary notions of the resistance offered to the passage of currents by conductors, and the phenomenon appears to be more readily explicable on the supposition that the structure of the nerve, and especially of its sheath, may be more delicate in those parts which are more protected, and that it consequently there more readily responds to impressions.

457. After death the excitability of the nerves dies out centrifugally, the part in proximity to the muscles remaining longest excitable; but Rosenthal has shown that immediately after death the excitability of the nerve is for a short period considerably exalted, and that this exaltation is shorter in duration in proportion to the distance of the portion of nerve examined from the muscle.

458. We now come to the consideration of the laws which regulate the contraction of muscles when a stimulus is applied to their nerves. It has long been well known that though contraction of a muscle usually occurs at the moments of opening and closing a current of electricity passed through the nerve supplying it, yet that this is not constant, the contraction failing sometimes at the moment of closing, and sometimes at the moment of opening the current. The singularity of this phenomenon has attracted the attention of many observers; and the names of Ritter and Nobili, Matteucci, Du Bois-Reymond, Eckhard, and Pflüger deserve especial mention for the light which they have thrown upon this obscure and difficult department of physiology. From their observations and from those of many other experimenters, it is now ascertained that the effects produced upon the muscle are dependent—1st, upon the direction of the electrical current passed through the nerve, whether centrifugal, *i.e.* from the origin to the periphery of the nerve (Fig. 95), or centripetal, *i.e.* from the periphery towards the origin (Fig. 96); 2ndly, upon the state of excitability of the nerve; and 3rdly, upon the strength of the current. Ritter and Nobili, in whose observations the strength of the current was disregarded, endeavoured to show that a definite succession of results followed the application of the electrical stimulus, according to the direction and the excitability of the nerve. Ritter, operating on Frogs, the excitability of whose nerves departed more slowly after death or excision, was able to distinguish six stages; whilst Nobili, operating in the warmer climate of Italy, could distinguish only four. The following tabular arrangement taken from Funke will show the relations of the contraction of the muscle to the degree of excitability remaining in the nerve, and to the direction of the current:—

FIG. 95.

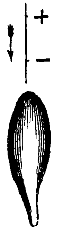
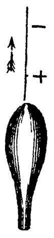


FIG. 96.



RITTER AND NOBILI'S LAW OF CONTRACTION.

C *indicates closure of the current;* O *indicates opening of the current, or breaking contact.*

Grade of Excitability of the Nerve.	Ascending or Centripetal Current.	Descending or Centrifugal Current.
I. (Ritter)	C, Contraction O, Rest	C, Rest. O, Contraction.
II. (Ritter)	C, Contraction O, Slight Contraction	C, Slight Contraction. O, Contraction.
III. (Ritter) I. (Nobili)	C, Contraction O, Contraction	C, Contraction. O, Contraction.
IV. (Ritter) II. (Nobili)	C, Weak Contraction (Ritter) Rest (Nobili) O, Contraction	C, Contraction. O, Slight Contraction.
V. (Ritter) III. (Nobili)	C, Rest O, Contraction	C, Contraction. O, Rest.
VI. (Ritter) IV. (Nobili)	C, Rest O, Rest	C, Slight Contraction. O, Rest.

From this Table it is apparent that in the highest grade of excitability of the nerve, the centripetal current induces contraction only on closure of the current, none occurring on opening it. Contraction on opening the current first happens in the second stage, *i.e.* when the excitability of the nerve is somewhat diminished, and then only weakly. In the 3rd stage of excitability of Ritter, the 1st of Nobili, the vigour of the opening and closing contraction is about equal. In the 4th grade, the closing contraction is weak, the opening strong. In the 5th stage, there is no contraction on closure, but it occurs on opening the current; whilst in the 6th and last stage no contraction follows either the closure or the opening of the current. For the descending or centrifugal current, the phenomena present themselves in an inverse order,—in the 1st or highest stage of excitability, there is contraction only on opening the current—then weak contraction on closure, as well as contraction on opening—then contraction of equal strength at both periods—then contraction at both periods, though weaker on opening the current—then contraction only on closure; and finally, in which respect it differs slightly from the effects of the centripetal current, weak contraction on closure of the current. From the preceding Table, the statement of Nobili, who only experimented during the last four stages of irritability, becomes intelligible, that there is essentially only one strong contraction for each direction of the current; an opening contraction being the most marked with the centripetal current, and a closing contraction with the centrifugal current.

459. Heidenhain* and Pfluger,† in following up this train of research, now showed that in freshly-prepared nerves, whose *excitability was therefore of the highest grade*, the law of contraction was dependent upon the strength of the current; and the phenomena have been thus formularized by Pfluger:—

Strength of Current.	Direction of Current.	
	Centripetal.	Centrifugal.
Weak	C, Contraction . . O, Rest.	C, Contraction. O, Rest.
Moderate . .	C, Contraction . . O, Contraction . .	C, Contraction. O, Contraction.
Strong . . .	C, Rest. . . . . O, Contraction . .	C, Contraction. O, Weak Contraction.

Thus beginning with currents so feeble that no contraction was induced either on making or on breaking contact in very excitable nerves, Pflüger found that on passing a slightly stronger, but still weak current, in a centripetal direction, contraction first occurred on closure, but none on opening. With currents of moderate strength, contraction occurs both on closing and opening the current; and lastly, if the current exceed a certain strength, no contraction occurs on closing, though it is well marked on opening the current.* If the same experiments are repeated with the centrifugal current, we obtain with the weakest current contraction on closure alone (exceptionally also on opening); with moderately strong currents, contraction both on opening and closure; and with strong currents, the closing contraction preponderates with centrifugal currents, and the opening contraction with centripetal. It has been already stated that when an electrical current is passed continuously through a portion of nerve, the condition termed by Du Bois-Reymond 'electrotonus' is established, and that *the portion of nerve at and near to the positive pole has its excitability diminished, whilst that portion at and near to the negative pole has its excitability exalted.* To the former condition the term 'anelectrotonus,' and to the latter the term 'cathelectrotonus,' has been applied by Pflüger. If either of these two conditions pass beyond a certain limit of intensity, the nerve ceases to be able to conduct an impression. Now the explanation which Pflüger has given of the law of muscular contraction is based on the following facts, the truth of which he has taken great pains to substantiate. He lays it down as a fundamental proposition that "a given portion of nerve becomes excited by the establishment of Cathelectrotonus, and by the disappearance of Anelectrotonus; whilst the disappearance of Cathelectrotonus, and the supervention of Anelectrotonus, are of none effect." In other words, when a constant current is transmitted through a nerve, the excitation produced by the change in the intensity of that current does not occur either on closing or on opening the current in all parts of the nerve affected by Electrotonus indifferently, nor even in all points of the intrapolar portion; but on closing the current the excitation inducing contraction of the muscles originates exclusively in the neighbourhood of the negative electrode, where the condition of Cathelectrotonus is established; and on opening the current in the neighbourhood of the positive electrode, where the condition of Anelectrotonus disappears. The immediate cause of the excitation is in the first instance the modification in the molecular arrangement at the Cathode, which is expressed by the increased excitability of the nerve around that point. In the second instance, the cause of the excitation is in the passage of the nerve at the Anode from the state of Anelectrotonus into the condition which it assumes after the opening of the current. The tetanizing influence of weak, constant currents during their closure, is believed by Pflüger to proceed, like the contraction on closure of the current, from the cathelectrotonized portion.

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* Heidenhain, in "Archiv f. Phys. Heilk.," 1857, p. 442.

† Pflüger, "Archiv f. Path. Anat.," band xiii.; and "Untersuchungen über d. Physiologie des Electrotonus," Berlin, 1859.

460. With the aid of the foregoing theory, the law of muscular con-

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* In the recent essay of Valentin ("Die Zuckungsgesetze des Lebenden Nerven und Muskels," Leipzig, 1863), it is maintained that the chief, and perhaps the only law of muscular contraction produced by electrical excitation of the active and uninjured living nerve, is that contraction of the muscle occurs with currents of moderate strength only on closing, and not on opening, the circuit, no matter in which direction the current flows; and when other effects occur, they are entirely due to injuries inflicted on the nerve in the process of preparation. Stronger currents modify this fundamental law; they induce not only opening but closing contractions, the former being less strong and energetic than the latter. Very strong currents (as with eight or more Grove's cells) passed through uninjured nerves, cause contraction with a descending current only on closure, and slight contraction with an ascending current on opening. Budge ("Virchow's Archiv," 1863, p. 282), however, declares that, with very strong currents (as from 12 to 25 Grove's cells), contraction occurs both on opening and closing the current, whichever way it may be directed through the nerve. It is plain, from these discrepancies, that all the disturbing causes have not been ascertained or attended to, and that further investigation is needed before Pflüger's law can be held to be a correct expression of the facts.

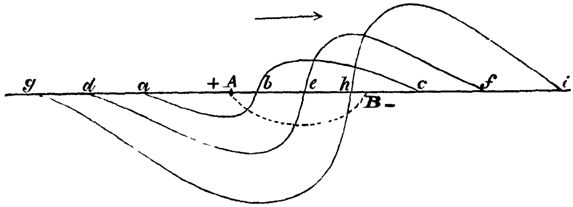
traction, with many of its apparent exceptions, can be explained in a very perfect and remarkable manner. Thus it will be seen, on a reference to the Table just given, that with weak inverse, or centripetal currents, contraction on closing the current occurs, but none appears when strong currents are employed; and the reason of this is evident, since the contraction on closure is due to the establishment of Cathelectrotonus, which here takes place above the anelectrotonized portion. When the current is feeble, the anelectrotonized portion (whose excitability is lowered) propagates the excitation descending from above, without any diminution; but if strong currents are employed, the portion of nerve in Anelectrotonus is of wider extent; and its excitability is so far diminished that it loses the power of conduction, and is consequently unable to transmit the excitation which originates as before at the Cathode on the closing of the current. Again, the contraction on *opening* the centripetal current first occurs when the force of the current is somewhat stronger than in the former case, but subsequently increases with the strength of the current. The stimulus or excitation here is the disappearance of Anelectrotonus, which with centripetal currents affects the portion of the nerve lying nearest to the muscle. That contraction occurs only on the use of somewhat stronger currents than in the former instance, results from the circumstance that it proceeds from a lower part of the nerve, whose excitability is much less than the more central part on which the excitation on closing the current operates (§ 456); and it appears also from hence that the disappearance of Anelectrotonus is, *per se*, a weaker stimulus than the establishment of Cathelectrotonus.—The increase of the opening contraction with increased strength of current, is simply due to the increase of Anelectrotonus at the lower pole, and the circumstance to be hereafter proved, that after the opening of the current the portion of Nerve previously affected by Anelectrotonus passes immediately into a state of increased irritability. Again, with descending or centrifugal currents, when these are weak, contraction usually first occurs on closure, though occasionally also on opening; whilst with currents of increased intensity the closing contraction constantly preponderates in energy: the opening contraction ultimately entirely disappearing. The occurrence of the closing contraction is clearly intelligible, since the stimulus on closure is the establishment of Cathelectrotonus, which here takes place in close proximity to the muscle. That it first occurs with currents of somewhat greater force than the closing contraction of the centripetal current, is due to the circumstance that the latter originates in the higher, more central, and therefore more excitable portion of the nerve (§ 456). As regards the opening contraction of the centrifugal current, the reason that it sometimes occurs earlier, sometimes later, than the closing contraction, is, that in one particular it is at a disadvantage, for the vanishing of Anelectrotonus is a feebler stimulus than the establishment of Cathelectrotonus; but, *per contra*, it is advantageously circumstanced, inasmuch as it affects a higher and therefore more excitable portion of the nerve; the contraction consequently occurs either on opening or on closing the current, as circumstances favour one or the other of these two conditions.—That the opening contraction with stronger currents diminishes and ultimately vanishes, results from the strong stimulus produced at the positive pole by the disappearance of strong Anelectrotonus; having, in order to reach the muscle, to pass through the intrapolar portion of nerve, and that portion of nerve which, whilst the current passed, was in a state of Cathelectrotonus. But these portions of nerve fall immediately after the opening of the current into a condition of diminished excitability, in which they become defective conductors of excitation, as will be hereafter shown. Thus Pfluger's theory appears in all respects to harmonize with the facts furnished by experiment, and gives a satisfactory explanation of their cause; whilst it is of great interest to know that the researches of Bernard, Fick, and others have shown in the most refined methods of inquiry, that the uninjured nerve of the living animal, when tested with *weak* currents, follows Pfluger's law of muscular contraction, giving, in whichever direction they are passed, contraction exclusively on closing the current.

461. We have hitherto been engaged in the consideration of the reactions of motor nerves to electrical stimulation, and but little progress has been made in ascertaining those of the sensory nerves, since we have no certain means of determining, in experimenting on animals at least, whether any impression is conveyed by a sensory nerve or not. That they do react is evident from the production of sensations of pain, light, and sound when currents are passed through the nerves usually conveying those impressions. Pfaff observed that the closure of a centripetal current through the Optic Nerve excited a more intense sensation of light than a centrifugal current, which is in accordance with the law of muscular contraction. No explanation, however, has been offered of the singular circumstance that during the passage of a centripetal current the colour is blue, whilst with centrifugal it is red. Pfluger maintains that here, as in the case of motor nerves, the effects produced are dependent upon the force of the current, except that, as might be expected from the direction in which they ordinarily conduct their impressions, there is a kind of inverse relation between them; and he gives the following experiment as a proof of his statement:—In a Frog poisoned with strychnia he removes the whole of the thigh with the exception of the Sciatic Nerve, to which a strong galvanic current is applied. If this be directed downwards, on closure contraction occurs in the muscle supplied by the nerve in the lower leg, but the animal remains quiet. On opening the current, however, the muscles are at rest. but the Frog becomes violently convulsed, indicating acute pain from the excitation of the sensory nerves. Inversely, with an upward current, the reflex convulsive movements of the body from pain only occur on closure, whilst the contractions of the lower limb only occur on opening the current. It is obvious that with a strong downward current no indication of pain occurs, because the stimulus originating at the Cathode, on making contact, cannot traverse the anelectrotonized portion, though violent pain is experienced on opening the current, because the stimulus arising from the disappearance of Anelectrotonus can be easily transmitted to the sensory ganglia, and, *vice versâ*, with the upward current.

462. We now pass to the consideration of the changes which are produced in the irritability of the Nerves during the passing of constant centripetal or centrifugal currents of varying strength. It has already been stated that the condition of the nerve at the Anode is one of depressed excitability, termed by Pfluger Anelectrotonus, and at the Cathode of exalted excitability, termed Cathelectrotonus. These con-

ditions extend to a certain distance *above and below* the Negative and Positive pole respectively, or as it may perhaps be better expressed, before and behind the poles. The Electrotonus which is established in the extrapolar portion of nerve at the Anode, or the Cathode, as the case may be, is designated Centripetal if it propagates itself from either pole towards the central end of the nerve; whilst it is termed Centrifugal when it propagates itself towards the muscle. Moreover, the Anelectrotonus and the Cathelectronus both involve a certain extent of the intrapolar portion of the nerve, so that the two zones of increased and decreased irritability abut upon one another in the intrapolar portion. The diminution and increase of irritability vary much in degree, and in the extent of the intra- and extrapolar portions of the nerve respectively that they involve, according—1, to the force of the constant current transmitted through the nerve; 2, to the length of the portion of nerve it traverses, that is, to the length of the intrapolar portion of the nerve; 3, to the distance of the portion of the nerve from the electrodes, the irritability of which is under examination; and lastly, 4, to the duration of the passage of the current. The following diagram will render the effects of variations in the force of the current, and the distance of the portion of nerve examined from the electrodes, intelligible:—

FIG. 97.

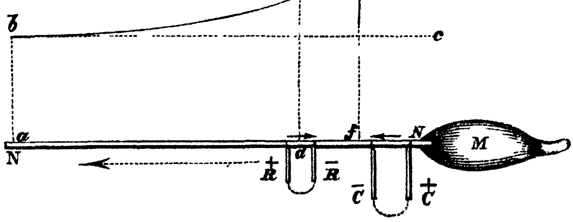


If a current be passed from A to B, either up or down the nerve, and the excitability of all parts of the nerve be examined—1, when the current is weak; 2, when it is of moderate strength, and 3, when it is strong—variations in the degree of excitability will be found to be present, which may be represented by the three curves, *a b c*, *d e f*, *g h i*, corresponding to the weak, moderate, and strong currents respectively. If we examine the curve *a b c*, indicating the modification of excitability existing with *weak* currents, it is apparent that there is a state of depressed excitability in the portion *a b*, shown by this portion of the curve being below the line of the nerve, and a state of increased excitability in the portion *b c*, which is shown by the curve being situated above the line. The point *b*, at which the curved line *a b c* cuts the line, is the point of indifference which separates the zones of Cathelectrotonus and of Anelectrotonus from one another. The form of the curve shows that from this point of indifference towards the Cathode, the positive phase, and towards the Anode, the negative phase of electrotonus, gradually rises in intensity, attains its maximum in the immediate neighbourhood of the two poles, then diminishes, and soon sinks to zero. Thus in the *extrapolar* portion the condition of exalted excitability diminishes on the one side, and the condition of depressed excitability diminishes on the other, in proportion to the distance from the Cathode and from the Anode respectively. Moreover, the curve gives an indication of the very unequal extent to which the *intra-*

polar portion is affected by the conditions of Cathelectrotonus and Anelectrotonus when weak currents are passed, the point of indifference *b* lying much nearer to the Anode than to the Cathode; so that nearly the whole of the intrapolar portion of the nerve, with the exception of a small piece near the Anode, is in a state of exalted sensibility, which has been already referred-to, when the tetanizing influence of weak currents was discussed. Again, in reference to the curve *d e f*, it will be seen that whilst preserving the general form of the curve *a b c*, it involves a larger portion of the nerve; and that the increase and decrease of excitability are greater in degree as marked by the height and depth of the curve above and below the line, whilst the point of indifference occupies a different position. Thus it appears that somewhat stronger currents affect, as we should anticipate, a larger extent of the nerve beyond the electrodes, and at the same time augment the irritability at the Cathode, and depress it at the Anode to a greater amount; whilst the position of the point of indifference shows that the intrapolar portion of nerve is, with moderately-strong currents, equally divided between the zones of Anelectrotonus and Cathelectrotonus. Lastly, the curve *g h i*, indicating the effects of the transmission of powerful currents, shows that the increase of excitability at the Cathode, and its decrease at the Anode, are still more strongly developed, and that the extent of the extrapolar portion of nerve affected is still greater, whilst the point of indifference is still further transposed towards the Cathode; so that, in this respect, the opposite effect is obtained to that which is produced by the passage of weak constant currents; and ultimately it has been found by Pflüger, that with very powerful currents indeed, the whole of the intrapolar portion of nerve is in a state of depressed irritability.

463. Simple and intelligible as these conditions appear, after the ingenious explanations of Pflüger have been fully comprehended, many phenomena present themselves, requiring much thought and patient investigation before they can be shown to be in accordance with and merely resultants of them: only one or two of them can here be considered, amongst which are—1. The change in the excitability of the nerve before and behind the ascending or centripetal current, or the condition of extrapolar centripetal Cathelectrotonus and extrapolar centrifugal Anelectrotonus. The evidence of the existence of extrapolar centripetal Cathelectrotonus, or of increased excitability of the nerve before (centrad) of the centripetal current—that is, between the Cathode and the centric extremity of the nerve—is only possible when very weak currents are employed. Its relations are shown in the following diagram:—

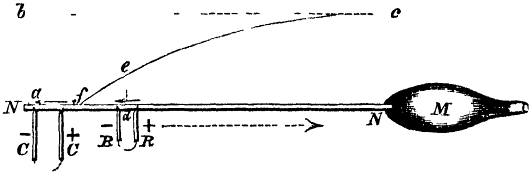
FIG. 98.



C C are the poles of a weak constant current capable of being infinitely varied in intensity at will, and directed centripetally, *i.e.* from the muscle towards the origin of the nerve. In order to test the change in the excitability of any antecedent portion of the nerve, as *d*, before and after the closure of the constant current, any stimulus of known and definite strength, chemical, mechanical, or electrical, may be applied at *d* before and after such closure, and the degree of contraction of the muscle, measured by a myographion, will indicate the increased or diminished excitability of the nerve at that point. Practically, the instantaneous shock of an *induction apparatus* is found to be the most convenient, since it also admits of infinite variation in intensity. It is termed the stimulating or exciting current, and its poles are therefore applied on either side of *d*, at R R. The exciting current, R R, is directed in the opposite direction to the polarizing one, C C, because its action as a stimulus is thereby virtually weakened; consequently, if it produce a greater effect after than before the closure of the constant current, it proves that the excitability of the extrapolar central portion must be greatly increased.—The weakest currents employed by Pflüger were not stronger than the normal current in a portion of the nerve itself; so that instead of the constant current, a portion of the Sciatic nerve of another frog might be applied to the transverse section, representing the — pole of C, and a point of the longitudinal section representing + C. In order, then, to ascertain the condition of excitability at *d*, after closure of the constant current, it is necessary, first, to determine, before its closure, the minimum strength of the exciting current, R R, which will give a just perceptible trace of contraction on closure, a tracing of which is taken on the myographion; the constant current is then closed, the same stimulus applied at R R, and a second tracing taken, when it will be found that, without exception, the amount of contraction exhibited by the second tracing is greater than that of the first, showing that the same stimulus produced a greater effect; or, in other words, that the nerve was more excitable. The same effect may be shown by chemical means (Eckhard), as by the application of a drop of a solution of common salt, before and after the closure of the constant current: in the former instance (before closure) a considerable interval elapses before the tetanizing influence of the solution supervenes; in the latter (after closure) it occurs directly. That the tetanizing influence is not dependent upon the constant current alone, is shown by applying it before permitting the contact of the saline solution with the nerve, or by inverting the direction of the current after contact with the solution, when the tetanus will disappear: though, if it were dependent upon the current alone, it ought to rise in intensity in the latter case, since, as we have already seen, the centrifugal direction is with weak currents the most favourable for the tetanizing influence.—If, instead of employing very weak constant currents, those of moderate strength be applied, a gradual increase in the excitability of the extrapolar portion of the nerve becomes apparent, until a maximum is attained; that is, until a stimulus applied at *d*, which before closure produced a minimum, after closure produces a maximum contraction of the muscle. But, if we still continue to increase the strength of the constant current at C C, a point is ultimately attained at which the portion of nerve affected with extrapolar centripetal electrotonus is no longer increased, but is actually diminished; so that the same stimulus applied after closure produces less contraction than when applied before, or may even become absolutely inoperative.—We see, then, that the force of the current is of great importance in influencing the condition of excitability in the extrapolar portion of the nerve, but it is not the only circumstance affecting it: it depends also, in part, upon the distance of the part of the nerve whose excitability is examined, from the electrodes of the constant current, as is shown in Fig. 97; whence it is apparent that the increase in the excitability is greater in proportion to the proximity of the part examined to the electrode, whilst at a certain distance from it it sinks to zero, the distance of the zero point again being in proportion to the intensity of the Cathelectrotonus, or to the strength of the current.

464. There is one other circumstance affecting the excitability of the nerve, namely, the length of the intrapolar portion; and Pflüger's experiments have shown that, though there are apparent exceptions with strong currents, the causes of which he has fairly explained, the rule holds good, that for currents of all grades of intensity, with increasing length of the intrapolar portion of nerve, the excitability of the portion of nerve situated before (centrad) the centripetal current increases.. As regards time, the state of increased excitability always attains its full intensity with great rapidity. Centrifugal extrapolar Anelectrotonus is the term employed by Pfluger to indicate the condition of the excitability behind the ascending or centripetal current, and therefore of the portion of nerve lying between the anode and the muscle. The following diagram will assist in rendering it intelligible:—

Fig. 99.



C C are the electrodes of the constant centripetal current, R R those of the exciting current; and the current in the latter is passed in the same direction as the polarizing, which tends rather to produce an increased condition of excitability in that portion of the nerve, and à fortiori, renders any observed diminution the more remarkable. The results of Pfluger's experiments on this myopolar portion of the nerve may be thus summarily stated:—The excitability of the portion of nerve lying behind the centripetal current shows itself under all circumstances, and with currents of all degrees of intensity, to be diminished. This diminution constantly increases with increased strength of the current, and extends farther and farther from the anode towards the muscle, decreasing, however, as the muscle is approximated, till it falls to zero; so that, as the figure shows, whilst *b c* indicates the line of normal excitability, supposed for the sake of simplicity to be equal throughout the whole length of the nerve, *f e c* indicates the curve of diminished excitability in the myopolar portion of nerve, the amount of diminution being greatest in the immediate neighbourhood of the anode, as at *f*, being less marked at *e*, and the excitability rising to its ordinary amount at *c*. —Moreover, this Anelectrotonus always increases with all strengths of the current, with the length of the intrapolar portion. As regards time, it appears to attain its maximum of development very slowly after closure of the constant current, extends very gradually over the portion of nerve affected by it, and gradually again decreases.—Extrapolar Centrifugal Cathelectrotonus (shown in Fig. 100) requires, after the full consideration that has been bestowed upon the two former conditions, but few words of explanation. It is the state of increased excitability which occurs before a descending or centrifugal constant current. It increases in intensity with the increase of the strength of the polarizing current, and with the length of the intrapolar portion of nerve, diminishes as we recede from the cathode towards the muscle, and at a certain distance, which is the more remote the stronger the current, becomes reduced to zero; it appears also to be developed immediately after the closure of the current.—Lastly, as regards the condition of excitability in Centripetal Extrapolar Anelectrotonus, it is diminished (as shown in the following diagram) in a manner so completely concordant with the previous laws, that no special description appears to be required. The influence of centripetal or inverse currents in preserving the irritability of motor nerves, and of direct or centrifugal currents in destroying their irritability, is very remarkable. By the passage of an inverse current, it is even possible to restore the irritability of a nerve which has been completely paralysed or rendered incapable of conducting stimuli by the passage of a direct current.

FIG. 100.

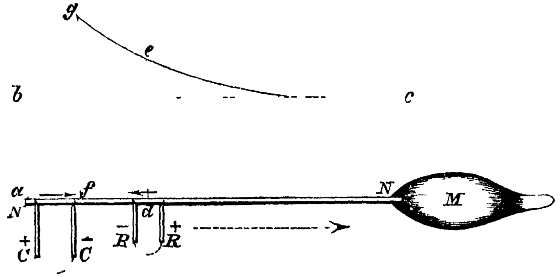
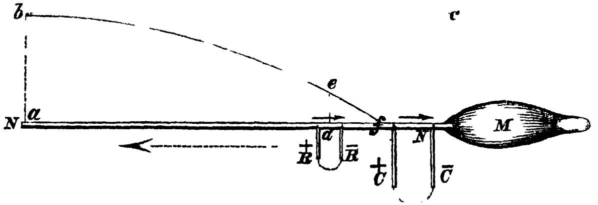


FIG. 101.



465. The explanation of the phenomena of the electrotonic state, and of the condition of increased and diminished excitability of the nerve in the neighbourhood of the negative and positive poles respectively, given

by Dr. Radcliffe,* is so ingenious, that it cannot here be passed-over in silence. He observes that under ordinary circumstances the exterior of the nerve is electrified positively, but that when the poles of a galvanic battery are applied to it, the *surface* of the nerve at and near the positive pole is charged with positive electricity, and that near the negative pole with negative electricity: the natural electricity of the former is consequently increased, since it is natural to suppose that the addition of *positive* electricity to the coating of the nerve will *induce* a corresponding *increase* in the *negative* electricity of the core of the nerve. At the negative pole the opposite conditions obtain. "This state of diminution and augmentation is what is spoken of by M. du Bois-Reymond as the electrotonic state." But, according to Radcliffe, with the presence, and, *à fortiori*, with the increase of electricity, the state of inaction of nerve and muscle concurs; whilst with the absence or decrease of natural electrical tension, action takes place. The reason, therefore, that when a centrifugal current is passed through a motor nerve, the portion adjoining the muscle is temporarily increased in irritability, as shown in § 460, is simply that its electrical tension is diminished. If, however, such a current is passed for any length of time (as 20 minutes) the irritability of the nerve, together with all traces of electrical tension, die out. If, on the contrary, a centripetal current be transmitted through a nerve, the irritability of the myopolar portion is diminished or suspended, no contraction occurring when the nerve is pricked or pinched. Such a current may be passed for hours, and yet at the expiration of that time the irritability of the nerve after the opening of the current may again be resumed, for its natural electrical relations have been kept up and even rendered more marked throughout the whole period of the passage of such a current.

[In drawing up the foregoing sections on the Electromotor properties of the Nerves, the Editor begs to acknowledge his great obligation to the excellent chapter on this subject in Funke's "Physiology," 4th edit. 1863, in which a very complete digest of the immense mass of literature which has accumulated during the last ten years, upon the electrical relations of the nervous system, will be found. A very interesting account of Pfluger's experiments and theory is contained in the "Med.-Chir. Rev." vol. ii. 1862, p. 1. For a good *résumé* of Eckhard's experiments and mode of testing the irritability of nerves during and after the passage of centripetal and centrifugal currents (which will be found to agree in all essential particulars with that here given), together with the application of these phenomena to the pathology of Epilepsy and other convulsive diseases, the reader is referred to the remarkable "Lectures" recently published by Dr. Radcliffe (1864).]

2. *Of the Spinal Cord and Medulla Oblongata;—their Structure and Actions.*

466. In our more detailed consideration of the functions of the several divisions of the Nervous System, it is desirable, for several reasons, to commence with the *Cranio-Spinal Axis;* which, as already pointed-out, may be considered as constituting the fundamental portion of this apparatus. The entire Axis is divided into its Cranial and its Spinal

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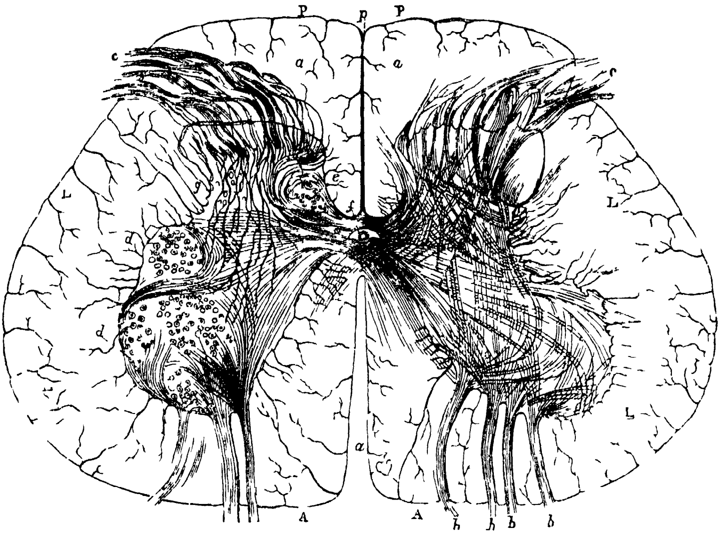
* "Lectures on Certain Disorders of the Nervous System," &c., 1864, p. 60.

portions, the passage of the Cord through the 'foramen magnum' of the occipital bone being considered to mark the boundary between them; and although the separation of the Medulla Spinalis from the Medulla Oblongata, which is thus established, is in itself purely artificial, yet it will be found to correspond completely with the natural division founded on their respective physiological attributes.

467. The *Spinal Cord*,[*] which extends from the margin of the foramen magnum to the first or second lumbar vertebra, and which is prolonged as the *filum terminale*[†] to the extremity of the sacral canal, is almost completely divided by the *anterior* and *posterior median fissures* (Fig. 102, *a*, *p*), into two lateral and symmetrical halves. The 'anterior median fissure' (*a*) is more distinct than the posterior, being wider at the surface; but it only penetrates to about one-third of the thickness of the Cord, its depth increasing, however, towards its lower part. The sides of the 'posterior median fissure' (*p*), on the other hand, are in closer approximation; but the division commonly extends to about half the thickness

FIG. 102.



Transverse section of *Spinal Cord*, through the middle of the lumbar enlargement, showing on the right side the course of the nerve-roots, and on the left the position of the principal tracts of vesicular matter —A, A, anterior columns; P, P, posterior columns; L, L, lateral columns; *a*, anterior median fissure; *p*, posterior median fissure; *b*, *b*, *b*, *b*, anterior roots of spinal nerves; *c*, *c*, posterior roots, *d*, *d*, tracts of vesicular matter in anterior column; *e*, tracts of vesicular matter in posterior column, *f*, spinal column; *g*, substantia gelatinosa.

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[*] The sketch given in the text of the Anatomy of the Spinal Cord, is chiefly derived from the statements of Prof. Kolliker, in his "Mikroskopische Anatomie" (band ii. §§ 115, 116), and of Mr. J. L. Clarke in the "Philosophical Transactions," 1851, 1853, and 1859.

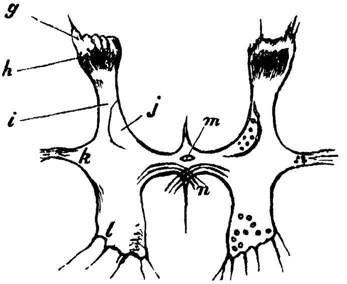
[†] The structure of the 'filum terminale' is in every respect essentially the same as that of the proper Spinal Cord, save that no nerve-roots are connected with it.

of the cord, being deeper towards its upper than towards its lower end. The two halves, therefore, are only united by a commissural band, which occupies the central part of the cord; and this is traversed by the 'Spinal canal' (*f*), which is continued downwards from the fourth ventricle, is about 1-100th of an inch in diameter, and according to Mr. Lockhart Clarke, is lined with a layer of columnar ciliated cells, whose attached extremities taper into delicate fibres, becoming continuous with the fibres of the connective tissue of the white columns.—At a little distance from either side of the posterior median fissure, and corresponding with the line of attachment of the posterior roots of the nerves, is the *posterior lateral furrow;* a shallow longitudinal depression, which marks-out the 'posterior columns' of the Cord (P, P) as distinct from the 'antero-lateral columns.' A corresponding furrow has been sometimes described as traversing the Cord in the line of the anterior roots of the nerves on either side; but this can scarcely be said to have a real existence; and the separation of the 'antero-lateral columns' into the 'anterior' and the 'lateral' columns (A A and L L) is only marked externally by the attachment of the nerve-roots. It is made more obvious internally, however, by the peculiar distribution of the *grey matter;* which, though by no means uniform throughout the Cord, usually presents (in a transverse section) the form of two somewhat crescent-shaped masses, whose convexities are turned towards each other, and are connected by the grey commissure, whilst their cornua are directed towards the surface of the cord; the posterior peak on each side nearly reaches the posterior lateral furrow, whilst the anterior, though the larger cornu, does not approach quite so near the surface. The grey matter is enveloped by the *white substance* of the columns, which are entirely composed of nerve-tubes, whose general direction is longitudinal.—The Spinal Cord of Man is by no means of uniform dimensions in every part of its length; and the proportions which the grey and white substances bear to one another in different parts, are extremely diverse. Two principal enlargements are seen in the cervical and lumbar regions, at the origins of the large nerves forming the brachial and crural plexuses; and these enlargements are chiefly due to an increase of the *grey* substance, which is comparatively deficient in the intervals. On the other hand, there is a regularly-progressive increase in the *white* substance, as we proceed from the lower to the higher portion of the cord; and this fact of itself serves to indicate the probability, that the longitudinal columns serve (as formerly supposed) to establish a direct connection between the Encephalic centres and the roots of the Spinal nerves.

468. The *grey matter* or *vesicular substance* of the Spinal Cord, which is best seen in transverse section (Figs. 102 and 103), is by no means uniform in its texture throughout. Its anterior cornua, which are thicker and shorter than the posterior, are of a uniform grey colour; and they consist of large well-developed nerve-cells (*d*, Fig. 102, and *l*, Fig. 103), which usually present many radiating processes that seem to inosculate together, with delicate nerve-fibres of medium fineness passing in various directions between them. The central portion, which contains the canal, and which also forms the commissure, has a similar composition; but the cells are smaller, though still having long branching radiations; and the fibres are extremely fine, their tubularity being often indistinguishable.

The anterior portion of the commissure, however (*n*, Fig. 103), is purely fibrous, and is distinguished by some as the 'white commissure;' it does not, however, form an immediate connection between the two anterior columns, but brings each of them, as will be presently seen, into relation with the vesicular matter of the anterior cornu of the opposite side. The posterior cornua (Fig. 103, *g h i j*), longer and narrower than the anterior, are divided by Mr. Lockhart Clarke into two parts, the Caput and the Cervix Cornu. The Caput Cornu (*g h*), or bulbous extremity of the horn, consists of an outer and comparatively transparent *gelatinous* portion (*g*), and of an inner and more opaque portion (*h*). The former contains nerve-cells of various shape and size, often multicaudate, the caudate prolongations being continuous with nerve-tubules of small average size (varying from 1-5000th to 1-20,000th of an inch), running transversely, longitudinally, and obliquely. Mingled with them are blood-vessels, and probably some connective tissue. The inner or anterior portion of the Caput also contains longitudinal fibres, to which its opacity is chiefly due; transverse fibres which are continuous with the posterior roots of the nerves and with the longitudinal column of the cord, and cells which are for the most part of small size.[*] A remarkable column of ganglionic cells constituting the inner and anterior part of the Cervix cornu (*j*) has been described by Mr. Clarke under the term of the posterior vesicular column. The point of junction of the anterior and posterior cornua (*k*) is termed by the same observer the tractus intermedio-lateralis. It extends from the upper roots of the eighth cervical nerves to the lowest part of the dorsal region, but is most prominent about the first and second dorsal nerves. The posterior vesicular columns, on the other hand, are largest at the lowest part of the dorsal region.

FIG. 103.



Transverse section of the grey substance of the *Human Spinal Cord* at the level of the first dorsal Nerves:—*g*, gelatinous substance of Caput Cornu; *h*, dark interior of Caput Cornu; *i*, Cervix Cornu, containing, *j*, the posterior vesicular column; *k*, the tractus intermedio-lateralis; *l*, Anterior Cornu; *m*, Central Canal; *n*, Anterior Decussating Commissure.

469. The connection of the Nerve-roots of the Spinal Nerves with the several components of the Cord, and the course of the fibres after entering it, may be made-out partly by means of *sections*, and partly by following the course of individual fibres by ordinary microscopical dissection.[†] The following is an outline of the information which may thus be gained from a comparison of transverse and longitudinal sections (Fig. 102 *et seq*).—The bundles that form the Posterior roots (Fig. 102, *c*, *c*; Fig. 104, P, P, P) consist of three kinds, which differ from each other partly in direction, and partly in the size of their component filaments. The *first* kind, Fig. 104,

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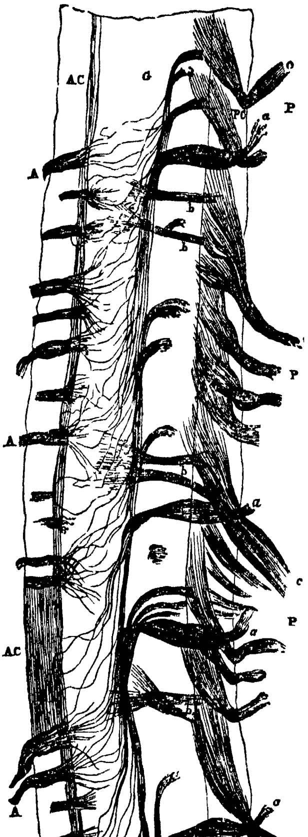
[*] See Lockhart Clarke, "Phil. Trans.," 1858, p. 249.

[†] Mr. J. L. Clarke has succeeded, by the adoption of a peculiar method of preparation (for which see "Phil. Trans.," 1859, Appendix, p. 458), in making sections of considerable dimensions, sufficiently transparent to allow the course of the fibres, and the contour of the nerve-cells and their prolongations, to be distinctly made-out.

a, *a*, *a* (which are more numerous in the upper part of the Cord), enter the posterior columns horizontally; and then, taking a longitudinal direction *down* the Cord, send fibres into the anterior grey substance (G), of which some bend upwards, and others downwards; part apparently becoming continuous with fibres of the anterior roots; whilst another part lose themselves among the fibres of the anterior columns, in which they may either proceed continuously to the head, or may pass-along for a limited distance only, to emerge in the nerve-roots of some other segment. The *second* kind of bundles, *b*, *b*, *b*, also traverse the posterior columns horizontally and obliquely inwards; their further course may be best traced in a transverse section (Fig. 102). These fasciculi, which are composed of remarkably fine and delicate fibres, interlace so as to form with each other an intricate plexus; and from this, straight and distinct bundles enter the posterior cornua along their whole breadth, crossing the 'substantia gelatinosa' both obliquely and at right angles. Having thus entered the vesicular substance of the Cord, some of the fibres become connected with multipolar ganglionic cells; others, after traversing it, emerge from it again, into either the posterior columns, or the posterior portion of the lateral columns; others pass towards the transverse commissure, through which they seem to make their way to the posterior and lateral columns of the opposite side; and others, again, form a fine network, which extends towards the anterior cornua. Of the fibres of a *third* set (Fig. 104, *c*, *c*, *c*), a part seem to become directly continuous with the fibres of the posterior columns; the larger proportion of them, however, cross these columns obliquely upwards, and enter the grey substance at different points; after passing into which, they can no longer

FIG. 104.



Longitudinal Section through Cervical enlargement of *Spinal Cord* of *Cat* —A C, anterior white columns; A C', portion showing the arrangement of the longitudinal fibres; P C, posterior white columns; G, grey substance between them (the vesicles omitted, to avoid obscuring the course of the fibres); A, anterior roots of the nerves, P, posterior roots, consisting of three kinds, the first, *a*, crossing the posterior columns horizontally, and then passing obliquely downwards, across the grey substance, into the anterior columns; the second, *b*, traversing the posterior columns horizontally, and then losing themselves in the grey substance; the third, *c*, for the most part becoming continuous with the longitudinal fibres of the posterior column; all, or almost all, ultimately entering the grey substance.

be clearly followed, although some of them appear to form loops and then return to the white columns.—The fasciculi of fibres which constitute the anterior roots (Fig. 102, *b*, *b*, *b*; Fig. 104, A, A), on the other hand, traverse the anterior columns of the Cord nearly horizontally, and in straight and distinct bundles, which do not interlace with each other, until they reach the anterior cornu of the grey substance; on entering this, they break-up into smaller bundles and separate fibres, which diverge in various directions; many unite with the larger multipolar ganglionic cells of the anterior horns of the grey substance; some pass-out again into the anterior, and others into the lateral columns of the same side; others, again, pass towards the anterior part of the commissure, in which they cross-over to the opposite side, entering its anterior and lateral columns; a considerable number plunge into the central substance of the grey cornu, and of these some become longitudinal, passing equally upwards and downwards, whilst others seem to traverse it horizontally, so as to come into relation (not improbably into actual continuity) with the posterior roots.[*]

470. Thus we see that there are two very distinct courses pursued by the Root-fibres of the Spinal Nerves, in the substance of the Cord; the first *transverse*, the second *longitudinal*. The fibres belonging to the former category traverse the Cord horizontally or obliquely, and appear to pass-out in the other set of roots connected with the same segment, either on its own or on the opposite side of the median fissure. Of those belonging to the latter, a small part appears to connect the posterior roots directly with the posterior columns, without passing into the vesicular substance; but the remainder of those belonging to the posterior roots, first enter the grey matter of the Cord, and then emerge from it either into the posterior column, or into the posterior part of the lateral column, of their own or of the opposite half of the Cord; and, in like manner, all the longitudinal fibres belonging to the anterior roots first enter the vesicular substance, and then pass-out from it into the anterior column, or the anterior part of the lateral column, of the same or of the opposite side. How far any of these longitudinal fibres proceed, however, either upwards or downwards in the Cord, must be acknowledged to be altogether undecided. It seems quite probable that *some* of them are (so to speak) properly longitudinal commissures, serving to connect the nerve-roots of one segment of the Cord, with the vesicular substance of another at a greater or less distance either above or below; and it has been recently maintained by several distinguished Neurologists, that *all* may be of this character, so that the Spinal Cord is the real centre of all the nerve-fibres connected with it.[†] The principal argument for

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[*] Those who are desirous of pursuing the structure of the Spinal Cord in more detail than can possibly be given in an elementary treatise like the present, are referred to the important work published by Stilling in 1856, entitled "Neue Untersuchungen über den Bau des Rückenmarks," in 3 parts, with an atlas; also to the "Untersuch. über den feineren Bau des Central Nerven-system des Menschen," by J. v. Lenhossek, Wien, 1855; to the researches of Bidder and Kupffer, "Ueber die Textur des Rückenmarks," Leipzig, 1857; to the valuable papers in the "Philosophical Transactions" for 1851, 1853, 1858, part i. p. 231, 1859, Part i. p. 437, by J. Lockhart Clarke; to the Translation by the Sydenham Society of the treatise of Schroeder v. d. Kolk, 1859; and to the recently published essay of Dr. C. Frommann, "Untersuch. üb. die Norm. u. Path. Anat. des Rückenmarks," Jena, 1864, 4 plates.

[†] See Budge, "Physiologie," 1862, p. 614, and Schilling, "De Med. Spin. Text.," Dorp. 1852. Schröder v. d. Kolk, Syd. Soc. Transl. 1859, pp. 44, 56.

this doctrine (which seems to have originated with the anatomical researches of Stilling and Wallach,* and to have been first put-forth on a physiological basis by Messrs. Todd and Bowman†), arises from the asserted difficulty of supposing that its longitudinal columns *can* transmit any considerable number of nerve-fibres from the Encephalon to the Spinal nerve-roots. Thus it is urged by Dr. Todd, that it is highly improbable that the only channel by which the Will can influence the spinal nerves, should be (as generally admitted) that afforded by the Anterior Pyramids; since the whole bulk of these pyramids on *both* sides, taken together, scarcely equals that of *one* of the anterior portions of the antero-lateral columns. Moreover, if there were a gradual giving-off of Encephalic fibres from the longitudinal columns into the roots of the nerves, the size of these columns ought progressively to diminish from above downwards; whereas it is asserted by Volkmann, who has strenuously upheld this doctrine (loc. cit.), that the size of the white columns presents no such diminution, but that it is everywhere proportional to the quantity of grey matter in the Cord. Thus in Serpents, the Spinal cord (as already noticed) is remarkable for its uniformity of dimension through its entire length, the absence of limbs preventing the necessity for an increase in the quantity of grey matter in any part, and the fibrous columns presenting a similar uniformity throughout; whereas, if the latter be really Encephalic, they should gradually dwindle-away from the head to the tail. Moreover it has been estimated by Volkmann, that the area of the whole Spinal Cord of a Boa, at its anterior part, is not more than *one-eleventh* part of the united area of the 221 pairs of nerves which are given-off from it. Further it is urged by Volkmann, that the white columns are absolutely smaller in the cervical region, than they are in the lower part of the Cord; so that they would not suffice to convey even the lumbar columns upwards to the Encephalon, much less to transmit the fibres of all the intervening nerves in addition.

471. These and similar statements, however, have been met by Prof. Kölliker (loc. cit.), whose researches have led him to a conclusion opposed to that of Volkmann, although he was at one time inclined to coincide with it. He has assured himself that *in Man*, the thickness of the white columns does augment from below upwards, and that the increase in the diameter of the Cord at the ganglionic enlargements is due to the augmentation of the grey matter only. Moreover, the diameter of the nerve-tubes in the Cord, especially at its upper part, is so much smaller than the diameter of the nerve-tubes of the Nerve-roots, that a large allowance must be made for this difference, in estimating the relative number of nerve-tubes in the fibrous columns of the Cord and in the Spinal Nerves; and he asserts from actual measurement, that it is by no means impossible for the fibrous strands of the former to contain all the nerve-tubes which issue from them in the latter. He has found himself unable, moreover, to detect *any* termination of the nerve-fibres in the vesicular substance of the spinal cord; and hence he thinks it probable that they all pass upwards to the brain.—On the other hand, the researches of Mr. J. L. Clarke, which have been carried in some respects to a greater

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* "Untersuchungen über die Textur des Rückenmarks," Leipzig, 1842.

† "Physiological Anatomy and Physiology of Man," part ii., 1845.

degree of minuteness than those of Prof. Kölliker, seem to confirm the belief that there *is* a set of fibres which never become longitudinal, and which, accordingly, have no other ganglionic centre than the vesicular substance of the segment of the Cord with which they come into immediate relation; whilst they also accord with those of Prof. Kölliker in rendering it extremely probable, that many of the longitudinal fibres of both roots do pass continuously upwards to the Encephalon, most of them after traversing the grey nucleus, but some of those of the posterior roots without even entering the vesicular substance, so that *these* cannot have their ganglionic centre in the Cord at all. If the latter be among the fibres which pass-up through the Posterior Pyramids into the sensory tract of the Crura Cerebri, their true ganglionic centres are the Thalami Optici.

472. That such is the real arrangement, is very strongly indicated by the analogous conformation of the gangliated cord of Articulated animals; for it may be stated with tolerable certainty, that some of the root-fibres of their nerves pass along the purely-fibrous tract of that cord (which is far more readily separated from the vesicular, than it can be in Vertebrata), directly to the cephalic ganglia, which they thus bring into direct communication with all the nerve-trunks connected with the gangliated cord; but that others, also becoming longitudinal, and running along those portions of the cord which intervene between and connect the ganglia of the different segments, pass into the nerve-trunks that emerge from ganglia at a distance of one, two, three, or more segments above or below: whilst a large proportion of the root-fibres have their ganglionic centres in the ganglia which they respectively enter; and, after coming into relation with its vesicular substance, pass-out again, either on the same or on the opposite side of the median plane.* Now the purely-fibrous tract of the ventral cord of the Articulata terminates in the Cephalic ganglia, which are homologous, as already remarked (§ 427, IV.), not with the whole Encephalon of Vertebrata, but with their 'sensory ganglia' alone; and thus analogy would lead us to suppose, that the fibrous strands of the Spinal Cord do *not* pass-on continuously to the *Cerebrum*, but really extend no further upwards than the Corpora Striata, Thalami Optici, and the other ganglionic centres in connection with them, which lie along the floor of the cranial cavity. This view will be hereafter shown (Sect. 3) to be in harmony with anatomical and physiological facts, which indicate that the Cerebrum only receives its impulses to action through the medium of the Sensory Ganglia, and that it reacts upon the muscular apparatus only through the same channel. That some of the afferent fibres of the spinal nerves should ascend continuously upwards to the ganglia of tactile sense, in Man and other Vertebrata, as well as in Articulated animals, would seem a legitimate deduction from the fact, that such continuity obviously exists between the olfactive, visual, and auditory nerves, and *their* respective ganglionic centres, no intermediate apparatus of vesicular matter being interposed in their course; and, as we have seen (§ 469), the existence of such a continuity

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* See "Princ. of Comp. Phys.," § 648.—The important facts here referred-to have been chiefly substantiated by the researches of Mr. Newport; a very important addition to his statements, however, has been recently made by M. Günther, who has demonstrated the actual continuity between the nerve-fibres and the caudate vesicles, in the ganglia of the ventral cord of the Leech.

in regard to a part of the fibres of the posterior roots of the nerves, is made extremely probable by the researches of Mr. J. L. Clarke.—A very remarkable confirmation, too, has been afforded to the doctrine of the constitution of the Spinal Cord here advocated, by the Pathological researches of Dr. Ludwig Türck;* who has shown that certain lesions of the Encephalon produce a degeneration of nerve-tissue in particular tracks, which may be traced continuously down the Spinal Cord, usually in the *anterior* column of the side affected, and in the *lateral* column of the opposite side; whilst, on the other hand, local lesions of the Spinal Cord, as from caries of the vertebræ, or from the pressure of tumours, produce a like degeneration in certain tracks of the posterior columns, and sometimes also of the lateral columns, ascending towards the Encephalon. Thus it appears that the *posterior* fasciculi are liable to this secondary degeneration in the *centripetal* direction only, and the *anterior* in the *centrifugal* direction only; the degeneration taking place, in each case, in the direction in which they ordinarily transmit nerve-force. The mixed endowments of the *lateral* columns are also indicated by these phenomena.

473. We are not required, however, by the adoption of this view of the constitution of the Spinal Cord, to regard its Cephalic fibres as of *a different order* from those which pass from one of its own segments to another; for, considering the whole of the Cranio-Spinal axis as *one series of centres*, receiving the terminations of all the nerves, its longitudinal fibres are equally *commissural*, whether they establish the connection between the nerve-roots and vesicular matter of two adjacent segments, or whether they bring into the same structural relation the parts which are furthest removed in position. And thus we may regard all impressions upon the afferent nerves as first operating upon it (affecting the consciousness, or not, according as they reach the Sensory Ganglia, or are arrested in their progress thither); and all motor impulses, whether purely-reflex, or originating in volitional direction or emotional excitement, as issuing immediately from it through the motor trunks.—If such be the case, it does not seem at all improbable that there should be a difference in different tribes of animals, as to the proportion of fibres which have their centres in the Spinal cord and in the Sensorial centres respectively; for in those whose ordinary movements of progression, &c., are independent of sensation, being performed through the reflex action of the spinal cord, it might be expected that the chief connection of the spinal nerves should be with its own ganglionic substance, and that the bulk of the fibrous columns should be composed of commissural fibres resembling those which intervene between the separate portions of the ganglionic tract of the ventral cord of Articulata; whilst in like manner it might be anticipated that in Man, so large a part of whose movements are performed in obedience to a mental stimulus and under the guidance of sensation, the longitudinal strands should be chiefly composed of fibres that directly connect the sensorial centres with the roots of the spinal nerves. Such a difference would appear, from the comparative researches

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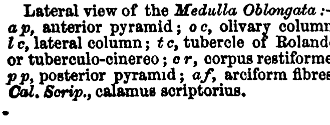
* See his Memoir 'Ueber secondäre Erkrankung einzelner Rückensmarksstränge und ihrer Fortsetzungen zum Gehirne,' in "Denkschriften der Kaiserlichen Akademie der Wissenschaften," Wien, 1851; also "Zeitschrift der Gesell. der Aertze zu Wien," band ix. heft 10.

of MM. Volkmann and Kölliker, to exist between the structure of the Spinal cord of the Horse and that of Man.

474. The *Medulla Oblongata*,* or cranial prolongation of the Spinal Cord, which brings it into connection with the Encephalic centres, is distinguished by the peculiar arrangement of its fibrous strands and of its nuclei of grey matter; and also by the peculiar distribution and endowments of the nerves connected with it. The anatomical boundaries usually assigned to it are the Pons Varolii above and the Occipital foramen below; but these limits are purely artificial, and for physiological purposes the course of its fibres must be traced much higher. The part thus marked-out has a bulb-like form, and presents, like the Cord of which it is the continuation, a posterior and an anterior median fissure. The former is deep and narrow, extending to the posterior border of a layer of commissural fibres which forms the floor of the anterior fissure. The latter is wider and less deep; and its continuity with the anterior fissure of the spinal cord is interrupted by the decussation of the Anterior Pyramids, which is marked externally by the crossing of from three to five bundles of fibres from each side over to the other. This decussation may be considered as the physiological boundary between the Medulla Oblongata and the Spinal Cord. The surface of each lateral half is furrowed by grooves, which assist in marking-out the several strands of nerve-fibres that may be distinguished on either side: these are—I. The Anterior Pyramids, or *Corpora Pyramidalia;* II. The Olivary Bodies, or *Corpora Olivaria;* III. The Lateral Columns; IV. The Tubercles of Rolando, or *Tuberculi Cinerei;* V. The Restiform Bodies, or *Corpora Restiformia;* otherwise called *Processus a Cerebello ad Medullam Oblongatam;* VI. The Posterior Pyramids, or *Corpora Pyramidalia Posteriora.* (See Fig. 105.)—The connections of these with the Brain above, and with the Spinal Cord below, will be presently traced. The vesicular substance, on the other hand, is principally aggregated in three pairs of ganglionic centres; of which the *anterior* forms the nucleus of the Olivary body, the *lateral* of the Restiform, and the *posterior* of the Posterior Pyramidal.

FIG. 105.



Lateral view of the *Medulla Oblongata*:—*a p*, anterior pyramid; *o c*, olivary column; *l c*, lateral column; *t c*, tubercle of Rolando, or tuberculo-cinereo; *c r*, corpus restiforme; *p p*, posterior pyramid; *a f*, arciform fibres; *Cal. Scrip.*, calamus scriptorius.

475. The *Anterior Pyramids* (I.) consist entirely of fibrous structure, and establish a communication between the 'motor tract' (Fig. 106, *m t*) of the Crura Cerebri, and the anterior and antero-lateral columns of the Spinal Cord. The principal part of their fibres decussate; and these, as they pass from above downwards, dip away from the anterior surface of the Cord, and connect themselves with its *middle* or *lateral* columns, instead of with its anterior, as was pointed-out by Rosenthal,† and more fully described by Dr. J. Reid.‡ And some fibres are stated by Mr. J.

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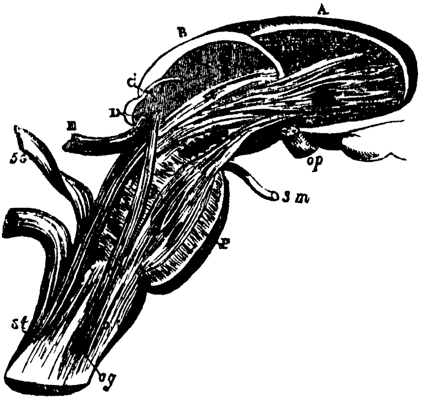
* For good accounts of the anatomy of the Medulla Oblongata, see Dr. John Reid in "Edinb. Med. and Surg. Jour.," 1841, and Mr. L. Clarke in the "Phil. Trans.," 1858, vol. i.

† "Ein Beitrag zur Encephalatomie," Weimar, 1815.

‡ "Edinb. Med. and Surg. Journ.," Jan. 1841; and "Physiol., Pathol., and Anat. Researches," chap. vii.

L. Clarke* to pass into the posterior columns and posterior grey substance. A small part of the fibres of the pyramidal columns, however, do not decussate, but proceed downwards on the same side, into the corresponding *anterior* columns of the Spinal Cord.—II. The *Olivary* bodies are composed of fibrous strands, enclosing a grey nucleus (Fig. 106, *o g*) on either side. The upward continuation of the former divides, while passing through the Pons Varolii, into two bands, one of which proceeds upwards and forwards as a part of the 'motor tract' (*m t*) of the Crus Cerebri, whilst the other (*o*) proceeds upwards and backwards to reach the Corpora Quadrigemina (C, D). The Olivary columns are continuous inferiorly with the antero-lateral columns of the Spinal Cord. Their vesicular nucleus, which is known as the '*Corpus dentatum*,' seems to be intimately connected with all the surrounding parts of the Medulla, chiefly through the arciform system which will presently be described; and Mr. Lockhart Clarke, though he has never been able to trace any immediate connection between the cells of the nuclear laminæ and the roots of the nerves—even in the case of the hypoglossal nerves which pass directly through them—yet is inclined to regard them as the co-ordinating centres for the different ganglia or nuclei of the Medulla Oblongata.† Schroeder v. d. Kolk is disposed from many considerations to regard these bodies as the nervous centres on which the symmetrical movements required in speech or the articulation of the voice are essentially dependent.‡ — III. The lateral columns (*l c*, Fig. 105), *Faisceaux intermédiaires* of Longet, decussate below with the anterior pyramids. Ascending, they assume the form of triangular columns, the apex of each appearing at the surface, the base being opposed to the one of the opposite side, and projecting, covered with grey substance, into the floor of the 4th ventricle. Behind, they are in contact with the restiform bodies, and in front with the olivary bodies. At their upper part they trifurcate, one portion curving outwards to enter the middle peduncle of the cerebellum, the other two separating from one another to allow of the passage of the superior peduncles of the cerebellum and part of the restiform columns, the inner one ultimately reaching the cerebral peduncles; the outer one forms a transverse commissure behind the *Corpora Quadrigemina.*—IV. The grey tubercle of Rolando (*t c*, Fig. 105)

FIG. 106.



Dissection of the *Medulla Oblongata*, to show the connections of its several strands:—A, corpus striatum; B, thalamus opticus; C, D, corpora quadrigemina; E, commissure connecting them with the cerebellum; F, corpora restiformia; P, P, pons varolii; *s t*, *s t*, sensory tract; *m t*, *m t*, motor tract; *g*, olivary tract; *p*, pyramidal tract; *o g*, olivary ganglion; *o p*, optic nerve; 3 *m*, root of the third pair (motor); 5 *s*, sensory root of the fifth pair.

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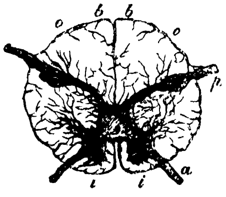
* "Phil. Trans.," 1858, p. 238. † Op. cit., p. 245. ‡ Op. cit., p. 148 *et seq.*

is simply the expanded extremity of the posterior cornu of the grey substance of the Spinal Cord now appearing on the surface.—v. The *Restiform* bodies each consist of fibrous strands (F, Fig. 106), enclosing a grey nucleus. The fibrous strands pass upwards into the Crura Cerebelli; whilst below they are chiefly continuous with the *posterior* columns of the Spinal Cord, having also some connection with the posterior part of the *middle* columns. These Cerebellar columns also communicate, however, with the *anterior* columns of the Spinal Cord by a band of 'arciform' fibres, whose connections were first distinctly described by Mr. Solly;* of these there is a superficial set which unites itself with the pyramidal columns, and a deep set which comes into relation with the olivary.—vi. The *Posterior Pyramids* are scarcely distinguishable externally from the Restiform bodies, of which they were formerly described as a constituent part; they form, however, the immediate boundaries of the posterior median fissure; and whilst superficially marked-off from the Restiform bodies by a slight groove, are more completely separated from them by their anatomical relations to the parts above and below. Their fibres establish a connection between the sensory tract (*s t*, *s t*) of the Crura Cerebri, and the posterior part of the *lateral* columns of the Spinal Cord, some of them passing also into its posterior columns. These fibrous tracts are stated by Mr. Solly† and Dr. Radclyffe Hall‡ to decussate, partially at least, whilst passing through the Pons Varolii. The arciform fibres (*a f*, Fig. 105) here seen crossing the Medulla nearly at right angles, just below the olivary bodies, which indeed they partly cover, have been shown by Mr. J. L. Clarke to be only a superficial portion of a very important and extensive order of commissural fibres (well seen in Figs. 110-112), the bulk of which is much more deeply placed, and which not only connect the opposite halves of the Medulla Oblongata by traversing the raphé, but at the same time form the means of communication between all the parts of each separate half, the net-like arrangement of the fibres being everywhere interspersed with innumerable cells of varied shape and size, from which many of the fibres may be seen to arise.—The gradual development of the several centres of grey substance in the Medulla Oblongata, and the relations which they bear to the Cerebral nerves, most of which take their origin from this part of the Spinal axis, may be rendered intelligible by a comparison of the following diagrams. The first section here shown (Fig. 107) is made at the level of the lower fibres of origin of the first Spinal nerves. On comparing the shape and position of the grey substance with its appearance, as shown in Fig. 102, it will be observed that the whole of the grey substance is here placed more anteriorly than in that

FIG. 107.



Section made opposite First pair of Cervical Nerves.—The following references indicate the same parts in Figs. 107–113:—*a*, anterior, *p*, posterior root of Spinal Nerve; *i i*, anterior white column; *o*, posterior white column below, but in the higher sections restiform body; *b, b*, posterior pyramids; *e*, grey Tubercle of Rolando; *Hg*, Hypoglossal Nerve; *Sp. Ac.* Spinal Accessory Nerve; *V*, Pneumogastric Nerve; *gp*, Glosso-pharyngeal Nerve.

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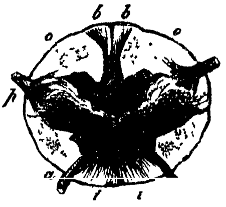
* "Philosophical Transactions," 1836.

† "The Human Brain," 2nd edit., p. 243.

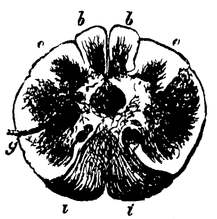
‡ "Edinb. Med. and Surg. Journ.," July 1847, plate vii.

FIG. 108.



Section passing through upper fibres of origin of First pair of Cervical Nerves.

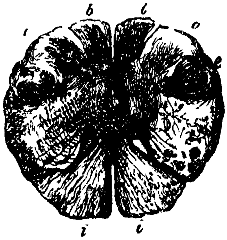
FIG. 109.



Section passing a quarter of an inch below Olivary bodies.

section; that the posterior white columns (*a* and *b*) are of large size, whilst the anterior and antero-lateral columns are comparatively small. In Fig. 108 the grey substance is seen to have relatively increased in size. On each side of the posterior median fissure a remarkable longitudinal column (*b*), containing grey matter in its interior, termed the 'pyramidal column,' is beginning to appear; a second swelling, situated on the Cervix a little more externally to that just mentioned, indicates the commencing appearance of the restiform nucleus; still more externally, the Caput Cornu may be seen to be detached and thrown aside from the rest as a distinct mass, which is traversed successively by the vagus and glosso-pharyngeal nerves, and then becomes the principal nucleus of the sensory root of the 5th pair. The decussation of the fibres of the anterior column is also here well seen. In the next section (Fig. 109), made about ¼ of an inch below the olivary bodies, the grey matter of the posterior pyramids (*b*) on either side of the posterior median fissure, is seen to have considerably increased in size; the slight swelling at the base of the Cervix is also now much larger, and has become the grey nucleus of the restiform bodies (*o*), whilst what was the Caput Cornu is pushed still further forwards, and forms a great mass of grey matter at the side of the cord, known as the Grey Tubercle of Rolando (*e*, Figs. 110, 111). The commissural direction and arrangement of the fibres of the anterior pyramids are also still apparent. On making a section just below the olivary bodies (Fig. 110), the grey matter is found to occupy almost the whole of the posterior pyramids (*b*), and a large portion of the restiform bodies (*o*), whilst a most delicate and complex system of interlacing fibres surrounds the central canal. The grey tubercle of Rolando having increased in size, and reached the surface of the Medulla, appears as a dark streak (*t c*, Fig. 105); the portion of the anterior column which does not decussate has been left white on the right side of this drawing. Two minute dark spots may be noticed near the bottom of the posterior fissure; these are imbedded in the mass of cells forming the chief ganglionic centres of the Spinal Accessory nerve, though other and extremely fine rootlets belonging to these nerves may be traced, arising from the same part of the grey matter, and issuing with the posterior roots of the Spinal nerves as low down as the sixth or seventh cervical vertebra. Fig. 111 is taken from a section made through the lower part of the Olivary body. The posterior pyramids (*b*) still contain much grey matter, and the restiform nucleus and grey tubercle of Rolando are strongly defined. The small central canal has become closely approximated to the bottom

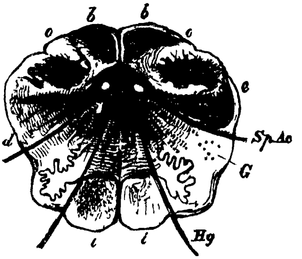
FIG. 110.



Section immediately below Olivary bodies.

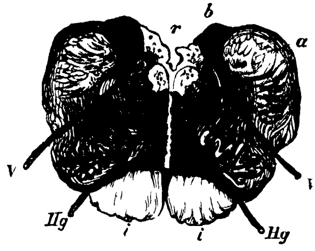
of the posterior median fissure, and on either side of it are the ganglionic masses from which the Spinal Accessory nerve takes its origin, whilst immediately in front of it are two dark spots indicating the ganglia of origin of the Hypoglossal Nerve. Anteriorly the windings of the corpus dentatum or olivary nucleus are visible, with a remarkable set of ganglionic cells indicated by G. The whole central part of the grey substance of the Medulla is shown to be composed of commissural bundles, constituting the deep system of arciform fibres described by Lockhart Clarke. The decussation of the anterior pyramids is here much diminished; for the fibres they derive from the lateral columns, which at first were their principal source, have become comparatively few; whilst those that proceed from the posterior columns and central grey substance have been gradually increasing in number, though not in a corresponding proportion. The section Fig. 112 is carried through the Medulla just at the point of the Calamus Scriptorius, and shows that the Hypoglossal ganglia have retreated somewhat backward, pushing the mass of ganglionic cells from which the Spinal Accessory arose, but which now constitute the origin of the *Pneumogastric Nerves* (v), to some extent outwards. The posterior pyramidal and restiform ganglia have increased in size, and by their lateral expansion form nearly one continuous mass on each side of the Medulla, which from the close interlacement of their fibres presents a spongy appearance, numerous cells being contained in the interstices. The section displayed in Fig. 113 is carried through the upper part of the Medulla Oblongata, and shows the Glosso-Pharyngeal arising at a higher level, but from the same series of ganglionic cells as those from which the Spinal Accessory and Pneumogastric roots have successively arisen, and which are now sunk beneath two new masses of vesicular substance from which the Auditory nerves take their origin. The Auditory nerve itself is seen to divide into two portions, one curving round the side of the Medulla, and forming the well-known transverse elevation on the floor of the Fourth Ventricle, the other dipping into the substance of the cord in front of the Restiform body to reach its ganglionic centre, formed by the summit of the posterior pyramid and apparently of part of the nucleus of the Pneumogastric nerve. The ganglionic cells which give

Fig. 111.



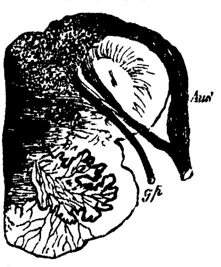
Section through lower part of Olivary body.

Fig. 112.



Section through point of Calamus Scriptorius.

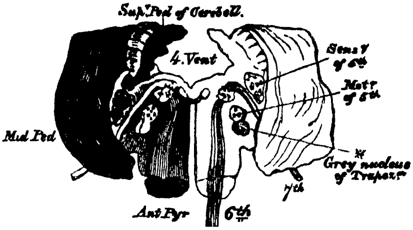
Fig. 113.



Section through upper part of the Medulla Oblongata.

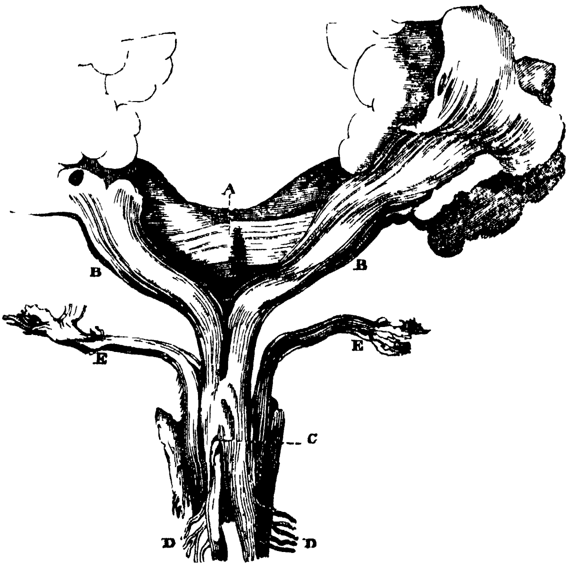
origin to the motor root of the 5th nerve are here very apparent, and may be traced, forming almost a distinct vesicular column in the Medulla as far down as to the level of the lowest roots of the Hypoglossal nerve. The deep origins of the 5th, 6th, and Portio Dura of the 7th, are shown in the section Fig. 114. The 6th and Portio Dura seem to form almost a loop, and to be continuous with one another through the ganglion from whence they arise, which is situated above but in the same line with that of the Hypoglossal. The motor and sensory roots of the 5th are separated from one another at their origin by the Portio Dura. The origins of the 4th pair of Cerebral nerves have been shown by Mr. Lockhart Clarke to be traceable on either side through the thin laminæ constituting the Valve of Vieussens, and through the columns forming the lateral boundaries of the Aqueduct of Sylvius, to near the floor of the fourth ventricle; whilst the 3rd nerve, the apparent origin of which is from the *locus niger* of the Cerebral peduncles, has been followed by Stilling to a grey nucleus underlying the Aqueduct of Sylvius. In order to complete the description of the origins of the Cerebral nerves, it is only requisite here to mention that the 2nd

FIG. 114.



Section made through the summit of the Medulla Oblongata.

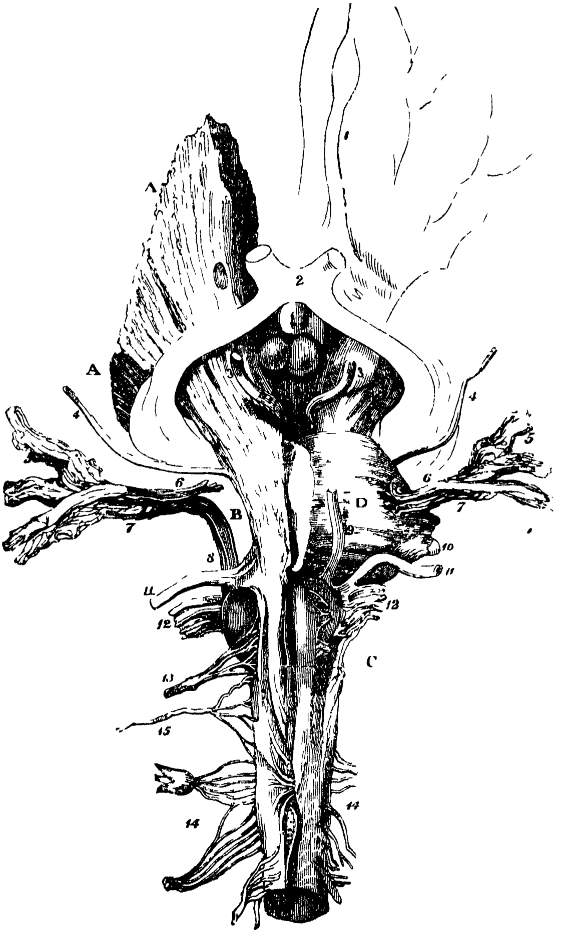
FIG. 115.



Course of the *Sensory tract* according to Sir C. Bell:—A, Pons Varolii; B, B, sensory tract separated; C, union of posterior columns; D, D, posterior roots of spinal nerves; E, sensory roots of fifth pair.

pair, or Optic nerves, arise from the posterior part of the Optic thalami and from the Corpora Quadrigemina; whilst the 1st pair, or Olfactory nerves, arise by three roots, the outer one appearing to be connected with the Corpus Striatum of its own side, the inner one with the Lamina Cinerea in front of the Optic commissure, and the middle one springing from a grey nucleus in front of the anterior perforated space.—It will thus be seen that the whole series of the Cephalic nerves, when followed

FIG. 116.



Course of the *Motor tract*, according to Sir C. Bell:—A, A, fibres of the Hemisphere, converging to form the anterior portion of the crus cerebri; B, the same tract, where passing the crus cerebri; C, the right Pyramidal body, a little above the point of decussation; D, the remaining part of the Pons Varolii, a portion having been dissected-off to expose B.—1, olfactory nerve, in outline; 2, union of optic nerves; 3, 3, motor oculi; 4, 4, patheticus; 5, 5, trigeminus; 6, 6, its muscular division; 7, 7, its sensory root; 8, origin of sensory root from the posterior part of the medulla oblongata; 9, abducens oculi; 10, auditory nerve; 11, facial nerve; 12, eighth pair; 13, hypoglossal; 14, spinal nerves; 15, spinal accessory of right side, separated from par vagum and glosso-pharyngeal.

to their origin, arise from grey ganglionic centres situated along the floor of or just below the fourth ventricle and the base of the brain. These, there can be little doubt, are more or less intimately connected with one another by longitudinal and transverse commissural fibres, and establish the existence of a Sensory tract, the activity of which is of fundamental importance, as will hereafter be shown, in the origination of ideas and of a certain class of movements which may be termed 'consensual' or 'sensori-motor.' The Pons is chiefly composed of transverse fibres which constitute the great commissure of the Cerebellum; and these fibres not only *surround* the longitudinal bands which connect the Cerebral mass with the Spinal Cord, but *pass through* them so as in some degree to isolate the two lateral halves from one another, and to form a complete septum between the anterior and posterior portions of each. These *anterior* and *posterior* tracts of the Crura Cerebri are probably essentially subservient to the *motor* and *sensory* functions. The general relations of the Sensory tract were represented by Sir Charles Bell in the accompanying diagram (Fig. 115), in which the Medulla is opened on its posterior aspect, the restiform columns separated and turned aside so as to bring into view the posterior pyramids, some of the fibres of which may be traced upwards into the Thalami Optici, whilst they pass through the posterior pyramids into the posterior portion of the *lateral* columns, and also into the *posterior* columns of the Spinal Cord. It will be seen, however, from the foregoing description, that the posterior and lateral columns of the Cord to a great extent terminate in the lower part of the Medulla Oblongata, and that the posterior pyramids and restiform bodies, with their grey nuclei, are essentially new formations, the real function of which is as yet only partially determined. The *Motor* tract (Fig. 116) is brought into view by simply raising the superficial layer of the Pons, and following upwards and downwards the longitudinal fibres which there present themselves. These fibres may be traced upwards into the Corpora striata, and downwards into the anterior pyramids and a portion of the olivary columns, so that they connect the Corpora striata with the *anterior*, and with the anterior portion of the *lateral* columns of the Spinal Cord.

476. *Nerves of the Spinal Axis.*—With the Spinal Cord (in its limited sense) there are connected thirty-one pairs of nerves; each of which corresponds to a vertebral segment of the body, and has two sets of roots, an anterior and a posterior, differing in their functional endowments, as already described (§ 443). The anterior roots are usually the smaller; and this is particularly the case with those of the cervical nerves, in which the posterior roots are of remarkable comparative size. In the first Cervical or 'sub-occipital' pair, the anterior roots are sometimes wanting; but there is then a derivation of fibres from the Spinal Accessory, or from the Hypoglossal, or from both. The two roots of the ordinary Spinal nerves unite immediately beyond the ganglion, which is situated on the posterior one; and the trunk thus formed separates immediately into two divisions,—the anterior and posterior,—each of which contains both afferent and motor fibres. These divisions, of which the anterior is by far the larger, proceed to the anterior and posterior parts of the body respectively; and are chiefly distributed to the skin and the muscles. The anterior branch is that which communicates with the Sympathetic nerve.—In addition to these, however, as we have seen, the cranial pro-

longation of the Spinal Axis is the centre of all the cephalic nerves, the functions of which, since they are for the most part distinguished by the peculiarity of their endowments, require to be separately noticed.

477. The pair of nerves commonly designated as the *Fifth* of the Cephalic series, or as the *Trigeminus*, is the one which more nearly resembles the ordinary Spinal nerves, than does any other of those originating within the cranium. It possesses two distinct sets of roots, of which one is much larger than the other; on the larger root, as on the posterior and larger root of the Spinal nerves, is a distinct ganglion, known as the 'Gasserian'; and the fibres arising from the smaller root, the number of which has been estimated at 9000 to 10,000, do not blend with those of the larger, until the latter have passed through this ganglion. The trunk of the nerve separates into three divisions,—the Ophthalmic, the Superior Maxillary, and the Inferior Maxillary; and it can be easily shown, by careful dissection, that the fibres of the smaller root pass into the last of these divisions alone. When the distribution of this nerve is carefully examined, it is found that the *first* and *second* divisions of it proceed almost entirely to the Skin and Mucous surfaces, only a very small proportion of their fibres being lost in the muscles; whilst of the branches of the *third* division, a large number are distinctly Muscular. Hence analogy, and the facts supplied by anatomical research, would lead to the conclusion, that the first two divisions are nerves of sensation only, and that the third division combines sensory and motor endowments. Such an inference is fully borne-out by experiment. When the whole trunk is divided within the cranium by the penetration of a sharp instrument (which Magendie, by frequent practice, was able to accomplish), evident signs of acute pain are given. After the incision has been made through the skin, the animal remains quiet until the nerve is touched; and when it is pressed or divided, doleful cries are uttered, which continue for some time, showing the painful effect of the irritated state of the cut extremity. The common sensibility of all the parts supplied by this nerve is entirely destroyed on the affected side. The jaw does not hang loosely, because it is partly kept-up by the muscles of the other side; but it falls in a slight degree; and its movements are seen, when carefully observed, to be somewhat oblique. If the trunk be divided on each side, the whole head is deprived of sensibility; and the animal carries it in a curious vacillating manner, as if it were a foreign body.—If the anterior or *Ophthalmic* branch only be divided, all the parts supplied by it are found to have lost their sensibility, but their motions are unimpaired; and all experiments and pathological observations concur in attributing to it sensory endowments only. The only apparent exception is in the case of the naso-ciliary branch, since there is good reason to believe that the long root of the ciliary ganglion and the long ciliary nerves possess motor powers; but these appear to be derived from the Sympathetic or from the 3rd pair. When the whole nerve, or its anterior branch, is divided in the rabbit, the pupil is exceedingly contracted, and remains immovable; but in dogs and pigeons it is dilated. The pupil of the other eye is scarcely affected; or, if its dimensions be changed, it soon returns to its natural state. The eyeball, however, speedily becomes inflamed; and the inflammation usually runs-on to suppuration and complete disorganization. The commencement of these changes may be

commonly noticed within twenty-four hours after the operation; and they appear to be due to the want of the protective secretion, which is necessary to keep the mucous surface of the eye in its healthy condition, and which is not formed when the sensibility of that surface is destroyed. —The *Superior Maxillary* branch, considered in itself, is equally destitute of motor endowments with the ophthalmic; but its connection with other nerves, through the spheno-palatine ganglion and its anastomosing twigs, may introduce a few motor fibres into it.—The *Inferior Maxillary* branch is the only one which possesses motor as well as sensory endowments from its origin; but its different subdivisions possess these endowments in varying proportions, some being almost exclusively motor, and others as completely of a sensory character. The latter is probably the nature of the Lingual branch; and there seems good reason to believe, as will hereafter be shown (§ 480), that this ministers not only to the tactile sensibility of the tongue, but to the sense of Taste. The muscles put in action by this division, are solely those concerned in the masticatory movements.—The 5th pair is connected, in different parts of its course, with a number of small ganglia belonging to the Sympathetic system. One of the most interesting of these ganglia is the *Ophthalmic* or *Ciliary* (Fig. 117, 29), which is the centre whence the eyeball derives its supply of nerves, sensory, motor, and sympathetic. This ganglion derives its sensory fibres by its 'long root' from the nasal branch of the Ophthalmic division of the 5th pair; its motor fibres, by the 'short root' from the 3rd pair; whilst by another small root, it is connected with the cavernous plexus of the Sympathetic system,* and is thus brought into relation with the Spinal axis; for, according to Budge,† these fibres of origin for the

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* The functions of this ganglion have been made the subject of particular investigation by Dr. C. Radclyffe Hall ("Edinb. Med. and Surg. Journal," 1846–48), whose most important results are as follows :—

1. The size of the ciliary ganglion is always in direct proportion to the activity of the iris, which in turn always bears a direct relation to the strength and acuteness of vision, and to the nocturnal habits of the animal, and implies a proportionate development of the internal vascular apparatus of the eye.

2. The ganglion is always more intimately connected with the 3rd pair than with any other; the size of the short root being always in direct relation to that of the ganglion, and the ganglion being sometimes a mere swelling on the trunk of the nerve.

3. The fibres derived from the 5th pair do not terminate in the ganglion, but pass onwards through it to the ciliary plexus.

4. In the Rabbit, the iris receives fibres from the 6th pair which do not pass through the ganglion; and it is through this that the contraction of the pupil is produced in that animal by irritation of the 5th pair, which will not produce any effect upon the pupil of the Dog, Cat, or Pigeon, so long as it does not affect the brain to the extent of producing vertigo, nor affect the visual sense in any other way.

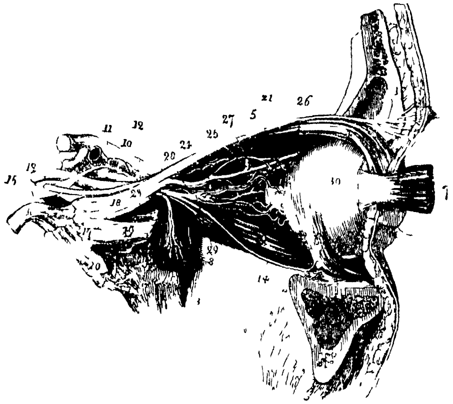
5. Irritation of the 5th nerve does not in any animal affect the action of the iris, *after* the division of the cerebral connections of all the other ocular nerves [this is denied by Budge], so that its influence over the movements of the iris must be reflected through the encephalic centres, not through the ophthalmic ganglion.

6. The function of the ganglionic centre itself, as a part of the Sympathetic system, seems to be to bring the 'organic actions' of the eyeball, especially its supply of blood, into harmony with its functional activity; this harmony being produced by the passage of the cerebro-spinal nerves through the ganglion, which excites the synergetic action of its own vesicles and nerve-fibres.—Irritation of the 3rd pair of nerves produces contraction of the pupil; irritation of the cervical portion of the Sympathetic, dilatation. On the other hand, paralysis of the 3rd nerve is followed by dilatation; paralysis of the cervical sympathetic (as by section), by contraction of the pupil.

† "Physiologie," 1862, p. 767.

Sympathetic nerve arise from two centres: first, from the Spinal cord between the 6th cervical and the 2nd dorsal vertebra (a part which he terms the Centrum Cilio-spinale Inferius), the fibres from which pass upward in the great cord of the Sympathetic; and secondly, from another centre situated in the Medulla Oblongata, in immediate proximity to the origin of the Hypoglossal nerve, the fibres from this source passing into the superior cervical ganglion. Valentin maintains that some of the fibres of the Inferior Cilio-spinal ganglion ascend in the trunk of the Pneumogastric.*

FIG. 117.



The *Nerves of the Orbit* seen from the outer side.—1, Section of the frontal bone; immediately behind the numeral is the frontal sinus, and, in front, the integument. 2. The superior maxillary bone; the section in front of the numeral exhibits the maxillary sinus. 3. Part of the sphenoid bone. 4. The levator palpebræ and superior rectus muscles. 5. The superior oblique muscle. 6. The inferior oblique muscle. 7. The ocular half of the external rectus muscle drawn forwards. 8. The orbital half of the external rectus muscle turned downwards. On this muscle the sixth nerve is seen dividing into branches. 9. The inferior rectus muscle. 10. The optic nerve. 11. The internal carotid artery emerging from the cavernous sinus. 12. The ophthalmic artery. 13. The third nerve. 14. The branch of the third nerve to the inferior oblique muscle. Between this and the sixth nerve (8) is seen the branch which supplies the inferior rectus; its branch to the ophthalmic ganglion is seen proceeding from the upper side of the trunk of the nerve, at the bottom of the orbit. 15. The fourth nerve. 16. The trunk of the fifth nerve. 17. The Gasserian ganglion. 18. The ophthalmic nerve. 19. The superior maxillary nerve. 20. The inferior maxillary nerve. 21. The frontal nerve. 22. Its division into branches to supply the integument of the forehead. 23. The lachrymal nerve. 24. The nasal nerve; the small nerve seen in the bifurcation of the nasal and frontal nerve, is one of the branches of the upper division of the third nerve. 25. The nasal nerve passing over the internal rectus muscle to the anterior ethmoidal foramen. 26. The infra-trochlear nerve. 27. A long ciliary branch of the nasal; another long ciliary branch is seen proceeding from the lower aspect of the nerve. 28. The long root of the ophthalmic ganglion, proceeding from the nasal nerve, and receiving the sympathetic root which joins it at an acute angle. 29. The ophthalmic ganglion, giving-off from its fore-part the short ciliary nerves. 30. The globe of the eye.

478. The *Third*, *Fourth*, and *Sixth* pairs, together make-up the apparatus of motor nerves, by which the muscles of the Orbit are called into action. The 3rd pair supplies the greater number of the muscles. The number of fibres in the 3rd nerve is about 15,000, in the 4th about 1100, in the 6th from 2000 to 2500;† the 4th being confined to the Superior Oblique, and the 6th to the External Rectus. Of these nerves, the 3rd pair is the only one which exhibits any appearance of sensibility when its trunk is irritated; but this sensibility is not nearly so great as

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* See Schiff, "Physiologie," p. 376.

† Rosenthal, "De Numero atque Mensura Microscop. Fibrillarum," Breslau, 1845.

that of the 5th pair; and as there is no reason to believe that it is really possessed by the 3rd in virtue of its direct connection with the nervous centres, it is probably imparted by the anastomosis of that nerve with the 5th,—some filaments of which may pass backwards as well as forwards, so as to confer sensibility on the trunk of the 3rd, above as well as beyond their point of entrance. Chauveau* observes that the deep or intra-cerebral portions of the motor nerves are quite incapable of being excited to action by direct stimulation; though on applying irritation to them at the point where they emerge from the cerebrum, movements can always be induced.—The peculiar mode in which those motor nerves ordinarily excite the muscles to action, under the guidance of the visual sense, will be considered in the next Section. Although commonly ranked as cephalic nerves, they have no direct connection with the Cerebrum; their real origin being from the upper part of the Spinal Axis. The roots of the 3rd pair may be traced into direct connection with the Corpora Quadrigemina; a fact of considerable physiological importance, as will hereafter appear.—The chief actions of a purely-*reflex* nature to which this group of nerves ordinarily ministers, are the government of the diameter of the pupil, which is accomplished through the Third pair; and the rolling of the eyeball beneath the upper lid during sleep, as well as in the efforts of sneezing, coughing, &c. But irregular movements of the eyeballs, which must be referred to the same group, are continually seen to accompany various abnormal forms of convulsive action.

479. The Portio Dura of the 7th pair, or Facial Nerve, containing about 4000 to 4500 nerve-fibres, was shown by Bell to be a purely motor nerve, chiefly distributed to the muscles of the face; it has hence been termed the Nerve of expression. In its passage through the Aqueductus Fallopii, it presents a gangliform enlargement, which is connected by the N. petrosus superficialis major with the spheno-palatine ganglion of the 5th, and by the N. petrosus superficialis minor with the otic ganglion.—By these branches the palatine muscles supplied by these ganglia receive their motor power, and some sensory fibres enter the facial, thus accounting for its sensibility when cut at its exit from that canal. It is also connected with the tympanic nerve of Jacobson proceeding from the glosso-pharyngeal, with the auricular of the Pneumogastric, and with the upper cervical nerves. The Portio Dura, besides the muscles of the face, supplies the stapedius, the auricular, occipital, stylohyoid, and the posterior belly of the digastric muscles. It does *not* supply the muscles of mastication. Its chorda tympani branch joins the lingual of the fifth, and has been shown by Bernard to be the nerve by which the submaxillary gland is excited to active secretion, while another branch is distributed to the parotid (§ 80).—Experimental as well as anatomical researches leave no doubt that the Portio Dura is the *general motor* nerve of the face; ministering to the influence of Volition and of Emotion, and also being the channel of the reflex movements concerned in respiration, as of other automatic actions of the muscles.

480. Although the functions of the *Glosso-Pharyngeal* nerve have been heretofore alluded-to in part, several questions still remain to be discussed in regard to them. Reasons have been given for the belief, that it is

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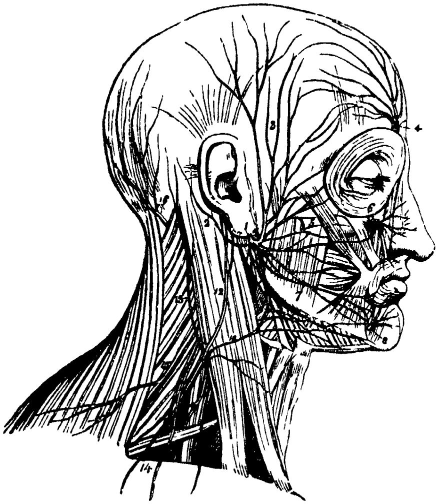
* "Journal de la Physiologie," tom. v., 1862, p. 272.

chiefly an afferent nerve,—scarcely having any *direct* power of exciting muscular contraction, but conveying impressions to the Medulla Oblongata, which produce *reflex* movements of the motor nerves concerned in deglutition (§ 69). This view of its function was deduced by Dr. J. Reid from minute anatomical investigation, and from a large number of experiments. Some experimenters assert, that they have succeeded in exciting *direct* muscular actions through its trunk; but these actions seem to be limited to the stylo-pharyngei and palato-glossi muscles.—Much controversy has taken place on the question, whether this nerve is to be regarded as ministering, partly or exclusively, to the sense of Taste; and many high authorities have ranged themselves on each side. The question involves that of the function of the Lingual branch of the 5th pair; and it is partly to be decided by the anatomical relations of the two nerves respectively. The Glosso-pharyngeal is principally distributed on the mucous surface of the fauces, and on the back of the tongue; but according to Valentin, it sends a branch forwards, on either side, somewhat beneath the lateral margin, which supplies the edges and inferior surface of the tip of the tongue, and inosculates with the Lingual branch of the 5th. On the other hand, the upper surface of the front of the tongue

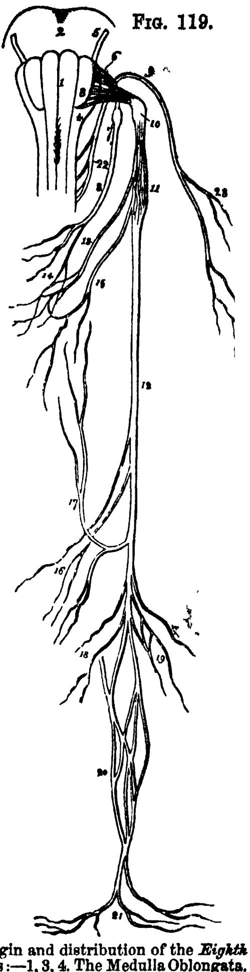
FIG. 118.



The distribution of the *Facial Nerve*, and the branches of the Cervical plexus:—1. The facial nerve, escaping from the stylo-mastoid foramen, and crossing the ramus of the lower jaw; the parotid gland has been removed in order to show the nerve more distinctly. 2. The posterior auricular branch; the digastric and stylo-mastoid filaments are seen near the origin of this branch. 3. Temporal branches, communicating with (4) the branches of the frontal nerve. 5. Facial branches, communicating with (6) the infra-orbital nerve. 7. Facial branches, communicating with (8) the mental nerve. 9. Cervico-facial branches, communicating with (10) the superficialis colli nerve, and forming a plexus (11) over the submaxillary gland. The distribution of the branches of the facial in a radiated direction over the side of the face, constitutes the pes anserinus. 12. The auricularis magnus nerve, one of the ascending branches of the cervical plexus. 13. The occipitalis minor, ascending along the posterior border of the sterno-mastoid muscle. 14. The superficial and deep descending branches of the cervical plexus. 15. The spinal accessory nerve, giving-off a branch to the external surface of the trapezius muscle. 16. The occipitalis major nerve, the posterior branch of the second cervical nerve.

is supplied by this Lingual branch. The experiments of Dr. Alcock, whose conclusions are borne-out by Dr. J. Reid, decidedly support the conclusion, that the gustative sensibility of *this* part of the tongue is chiefly due to the latter nerve, being evidently impaired by division of it. On the other hand, it is equally certain, that the sense of taste is not destroyed by section of the Lingual nerve on each side; and it seems also well ascertained, that it is impaired by section of the Glosso-pharyngeal nerve.—The pathological evidence bearing upon this point appears somewhat contradictory. Numerous cases have been recorded,* in which both common and gustative sensation were destroyed in the parts of the tongue supplied by the 5th pair, when that nerve was paralyzed; in some of these, the loss of the sense of taste appeared to extend itself to the base of the tongue, but then there was evidence that the Glosso-pharyngeal was involved in the paralysis. On the other hand, cases of paralysis of the 5th pair are related by Mr. Noble and by Vogt,† in which common sensation was lost, whilst the sense of taste remained in the same parts; and Mr. Noble relates another case,‡ in which there was loss of taste without impairment of common sensation. The cases of Mr. Noble and Vogt would seem to indicate that the 5th pair does not minister to the sense of Taste; but, as Dr. J. Reid has justly observed, we have no evidence that *all* the filaments of the 5th pair sent to the tongue were affected; and there is believed to be no case on record, in which the whole of the 5th pair, or of its 3rd branch, was found

FIG. 119.



Origin and distribution of the *Eighth Pair* of nerves:—1, 3, 4. The Medulla Oblongata. 1. The Corpus Pyramidale of one side. 3. The Corpus Olivare. 4. The Corpus Restiforme. 2. The Pons Varolii. 5. The Facial nerve. 6. The origin of the *Glosso-pharyngeal* nerve. 7. The ganglion of Andersch. 8. The trunk of the nerve. 9. The *Spinal Accessory* nerve. 10. The ganglion of the *Pneumogastric* nerve. 11. Its plexiform ganglion. 12. Its trunk. 13. Its pharyngeal branch forming the pharyngeal plexus (14) assisted by a branch from the glosso-pharyngeal (8) and one from the superior laryngeal nerve (15). 16. Cardiac branches. 17. Recurrent laryngeal branch. 18. Anterior pulmonary branches. 19. Posterior pulmonary branches. 20. Œsophageal plexus. 21. Gastric branches. 22. Origin of the Spinal Accessory nerve. 23. Its branches distributed to the sterno-mastoid muscle, 24. Its branches to the trapezius muscle.

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* See especially the cases recorded by Romberg, in "Müller's Archiv," 1838, heft iii.; Todd and Bowman, in "Physiological Anatomy," vol. i. p. 445; and Dixon, in "Med.-Chir. Trans.," vol. xxviii.

† "Medical Gazette," Oct. 25, 1834; and "Müller's Archiv," 1840, p. 72.

‡ "Medical Gazette," Nov. 21, 1835.

to be diseased after death, and in which during life the sense of Taste had been retained in the anterior and middle parts of the tongue. Hence these cases only serve to indicate what is probable on other grounds; viz., that the filaments which convey gustative impressions are not the same with those that minister to common sensation.—On the whole, then, it seems to be proved by anatomical and experimental evidence, that both the Glosso-pharyngeal and the Fifth pair minister alike to the *tactile* and to the *gustative* sense; and there is nothing in the pathological facts just noticed, that militates against this conclusion. There seems good reason to believe the Glosso-pharyngeal to be exclusively the nerve, through which the impressions made by disagreeable substances taken into the mouth are propagated to the Medulla Oblongata, so as to produce *nausea* and to excite efforts to vomit. The number of fibres in this nerve is about 3500.

481. The functions of the *Pneumogastric* nerve at its *roots* have been made the subject of particular examination by various experimenters; some of whom (for instance, Valentin, Longet, and Morganti) have concluded that it *there* possesses no motor power, but is entirely a sensory or rather an afferent nerve. According to these, if the roots, containing about 4000 smaller and 5000 larger tubules, be carefully separated from those of the Glosso-pharyngeal, and (which is a matter of some difficulty) from those of the Spinal Accessory nerve, and be then irritated, no movements of the organs supplied by its trunk can be observed: whilst, if the roots be irritated when in connection with the nervous centres, muscular contractions, evidently of a reflex character, result from the irritation; and strong evidences of their sensibility are also given. It has been further asserted that, when the roots of the Spinal Accessory nerve are irritated, no indications of sensation are given; but that the muscular parts supplied by the Pneumogastric, as well as by its own trunk, are made to contract, even when the roots are separated from the nervous centres; so that these roots must be regarded as the channel of the motor influence transmitted to them from the Medulla Oblongata. Where the Pneumogastric swells into the jugular ganglion, an interchange of fibres takes place between it and the Spinal Accessory; and it seems clear that the pharyngeal branches, which are among the most decidedly motor of all those given-off from the Pneumogastric, may in great part be traced backwards into the Spinal Accessory. —But, on the other hand, an equally numerous and trustworthy set of experimenters (among whom may be mentioned J. Reid, Müller, Volkmann, Stilling, Wagner, and Bernard) are opposed to this opinion; maintaining that the Pneumogastric has motor roots of its own; and affirming that irritation of the roots of the Spinal Accessory produces little or no effect on the muscles supplied by the trunk of the Par Vagum. In the careful experiments of MM. v. Kempen and Thiernesse,* the causes of these discrepancies have been elucidated, for they have shown that if irritation be applied to the roots of either the Spinal Accessory or Pneumogastric nerves, contractions occur in the œsophagus, in the constrictor muscles of the pharynx, and in the internal muscles of the larynx; and, in addition, when the Spinal Accessory roots were irritated, in the

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* "Bulletin de l'Acad. Roy. de Méd. de Belgique," 1863, tom. xvi. p. 184.

trapezius and sterno-mastoid muscles. If, however, the roots of the Pneumogastric nerves be divided, and irritation be again applied to the roots of the Spinal Accessory, no movements are observed except in the trapezius and sterno-mastoid muscles. Hence it would appear that in the former instance, the œsophageal and laryngeal movements were occasioned by a reflex action conveyed to the Medulla Oblongata by centripetal or sensory fibres in the Spinal Accessory, and reflected down to the muscles by motor fibres in the Pneumogastric nerves, the communication between the two nerves being effected by a chain of ganglionic nerve-cells in the Medulla. This view receives strong confirmation from another series of experiments performed by M. v. Kempen, who found that if the supposed communication in the Medulla between the two nerves were divided by a transverse section carried between their respective origins, irritation of the posterior cut surface of the Medulla or of the roots of the Spinal Accessory was only followed by movements in the sternomastoid and trapezius muscles; whilst, when the same irritation was applied to the upper extremity of the Medulla or to the roots of the Pneumogastric, contractions occurred in the muscles of the pharynx and larynx. Hence we may conclude that the Pneumogastric itself contains the motor fibres which act on the muscles of the pharynx, œsophagus, and larynx; although it probably receives additional motor fibres from the Spinal Accessory, and supplies that nerve with afferent fibres.

482. There can be no doubt that the *trunk* of the Pneumogastric is to be considered as a nerve of double endowments; although it is certain that these endowments are very differently distributed amongst its branches. That the nerve is capable of conveying those impressions which become *sensations* when communicated to the sensorium, is experimentally proved by the fact, that, when its trunk is pinched, the animal gives signs of acute pain: but it is also evident from the painful consciousness we occasionally have, of an abnormal condition of the organs which it supplies. Thus, the suspension of the respiratory movements gives rise to a feeling of the greatest uneasiness, which must be excited by impressions conveyed through this nerve from the lungs; and an inflamed state of the walls of the air-passages causes the contact of cold and dry air to produce distressing pain and irritation: yet of the ordinary impressions conveyed from these organs, which are concerned in producing the respiratory movements, and in regulating the actions of the glottis, we are not conscious. The same may be said of the portion of the nerve distributed upon the alimentary tube: for the pharyngeal branches are almost exclusively motor, the afferent function being performed by the glosso-pharyngeal; whilst the œsophageal and gastric are both afferent and motor, conveying impressions which excite reflex movements in the muscles of those parts, but which do not become sensations except under extraordinary circumstances.—The participation of this nerve in the operations of Deglutition, Digestion, Circulation, and Respiration, and the effects of injury to its trunk or branches, have already been considered in the account of those functions.*

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* For recent observations on the function of the Pneumogastric Nerve as a co-ordinator for the muscular movements occurring in swallowing, see Chauveau, "Journal de la Physiol.," tom. v. pp. 190 and 323; and for a very careful inquiry into the effects of section of this nerve in producing pulmonary lesions, see Boddärt in idem, pp. 442 and 527.

483. In regard to the functions of the *Spinal Accessory* nerve, also, there has been great difference of opinion; the peculiarity of its origin and course having led to the belief, that some very especial purpose is answered by it. It may be said to have three roots of origin (Lockhart Clarke), one from the anterior grey substance of the Spinal Cord, a second from the nucleus of the Hypoglossal nerve, and a third from the tract of vesicular substance in the Medulla Oblongata, common to it and the Vagus nerve. The trunk contains from 2000 to 2500 tubules. The predominance of motor fibres in its roots, its inosculation with the Pneumogastric, and its probable reception of sensory fibres from the latter, whilst imparting to it motor filaments, have been already referred-to (§ 481). As its trunk passes through the foramen lacerum, it divides into two branches; of which the internal, after giving-off some filaments that assist in forming the pharyngeal branch of the Pneumogastric, becomes incorporated with the trunk of that nerve; whilst the external proceeds outwards, and is finally distributed to the sterno-mastoid and trapezius muscles, some of its filaments inosculating with those of the cervical plexus. When the external branch is irritated, before it perforates the sterno-mastoid muscle, vigorous convulsive movements of that muscle and of the trapezius are produced; and the animal does not give any signs of pain, unless the nerve be firmly compressed between the forceps, or be included in a tight ligature. Hence it may be inferred that the functions of this nerve are chiefly motor, and that its sensory filaments are few in number. Further, when the nerve has been cut-across, or firmly tied, irritation of the lower end is attended by the same convulsive moments of the muscles: whilst irritation of the upper end in connection with the spinal cord, after section of the Pneumogastric Nerves (§ 481), is unattended with any muscular movement. Hence it is clear that the motions in the sterno-mastoid and trapezius muscles, occasioned by irritating it, are of a direct, not of a reflex character; though the movements which occur in the laryngeal and pharyngeal muscles, on irritation of the centric extremity, are unquestionably reflex in their nature.—According to Sir C. Bell, the Spinal Accessory is a purely Respiratory nerve, whose office it is to excite the involuntary or automatic movements of the muscles it supplies, which share in the act of respiration; and he states that the division of it paralyzes, as muscles of respiration, the muscles to which it is distributed; though they still perform the voluntary movements, through the medium of the spinal nerves. Both Valentin and Dr. J. Reid, however, positively deny that this is the case; and Dr. Reid's method of experimenting was well adapted to test the truth of the assertion.* The functions of this nerve have been made the subject of special examination by M. Cl. Bernard;† who has arrived

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* See his "Physiol., Pathol., and Anat. Researches," p. 151; and "Edinb. Med. and Surg. Journ.," Jan. 1838.

† 'Recherches Expérimentales sur les Fonctions du Nerf Spinal,' in "Archives de Médecine," 1844.—This Memoir, having gained the prize given by the Académie des Sciences for experimental physiology in 1845, has been printed in the "Recueil des Savants étrangers," tom. xi., 1851; and the author states that since the first publication of his researches, he has confirmed his original conclusions by the repetition and variation of his experiments. See also M. Bernard's "Leçons sur la Phys. du Système Nerveux," tom. ii. p. 279 *et seq.*, 1858.

at the conclusion that the Spinal Accessory is essentially a motor nerve, whose action is not exclusively requisite for the *ordinary* movements of respiration, these being provided-for by the Pneumogastric and ordinary Spinal nerves; but that its special function is to bring the respiratory movements into accordance with the requirements of Animal life, adapting the actions of the muscles of the larynx and thorax to the production of *voice*, or to general muscular *effort*. The internal branch, which is specially distributed, with the fibres of the Pneumogastric, to the pharynx and larynx, is peculiarly subservient to the former of these purposes; and the external to the latter. This conclusion is sufficiently in accordance with the results obtained by other experimenters, to be received as a probable explanation of the facts which have been observed by them.

484. The *Hypoglossal* nerve, or *Motor Linguæ*, is the only one which, in the regular order, now remains to be considered. This nerve contains from 4500 to 5000 nerve-fibres. That the distribution of this nerve is restricted to the muscles of the tongue, is a point very easily established by anatomical research; and accordingly we find that, long before the time of Sir C. Bell, Willis had spoken of it as the nerve of the motions of articulation, whilst to the Lingual branch of the 5th pair he attributed the power of exercising the sense of taste; and he distinctly stated, that the reason of this organ being supplied with two nerves, is its double function. The inference that it is chiefly, if not entirely, a *motor* nerve, which has been founded upon its anatomical distribution, is supported also by the nature of its origin, which is usually from a single root, corresponding to the anterior root of the Spinal nerves. Experiment shows that when the trunk of the nerve is stretched, pinched, or galvanized, violent motions of the whole tongue, even to its tip, are occasioned; and also that similar movements take place after division of the nerve, when the cut end most distant from the brain is irritated. In regard to the degree in which this nerve possesses sensory properties, there is some difference of opinion amongst physiologists, founded, as it would seem, on a variation in this respect between different animals. Indications of pain are usually given when the trunk is irritated after its exit from the cranium; but these may proceed from its free anastomosis with the cervical nerves, which not improbably impart sensory fibres to it. But in some Mammalia, the hypoglossal nerve has been found to possess a small posterior root with a ganglion; this is the case in the Ox and Cat, and also in the Rabbit; and in the latter animal, Valentin states that the two trunks pass-out from the cranium through separate orifices, and that, after their exit, one may be shown to be sensory, and the other to be motor. Hence, this nerve, which is the lowest of those that originate in the cephalic prolongation of the spinal cord generally known as the Medulla Oblongata, approaches very closely in some animals to the regular type of the spinal nerves; and though in Man it still manifests an irregularity, in having only a single root, yet this irregularity is often shared by the first cervical nerve, which also has sometimes an anterior root only.*—The Hypoglossal nerve is distributed not merely to the tongue, but to the muscles of the neck which are concerned in the movements of the larynx; and the purpose of this distribution is probably to associate

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* See Vulpian's 'Essay on the Posterior or Ganglionic Root of the Hypoglossal Nerve in various Animals,' "Journal de la Physiologie," 1862, p. 5.

them in those actions which are necessary for articulate speech. Though *all* the motions of the tongue are performed through the medium of this nerve, yet it would appear, from pathological phenomena, to have at least two distinct connections with the nervous centres; for in many cases of paralysis, the masticatory movements of the tongue are but little affected, when the power of articulation is much injured or totally destroyed; and the converse may be occasionally noticed. When this nerve is paralyzed on one side, in hemiplegia, it will be generally observed that the tongue, when the patient is directed to put it out, is projected *towards* the palsied side of the face: this is due to the want of action of the lingual muscles of that side, which do not aid in pushing-forward the tip; the point is consequently directed only by the muscles of the other side, which will not act in a straight direction, when unantagonized by their fellows. It is a curious fact, however, that the Hypoglossal nerve seems not to be always palsied on the same side with the Facial, but sometimes on the other. This has been suggested to be due to the origination of the roots of this nerve from near the point at which the pyramids of the medulla oblongata decussate, so that some of its fibres come-off, like those of the spinal nerves, without crossing, whilst others are transmitted to the opposite side, like those of the higher cephalic nerves; and the cause of paralysis may affect one or other of these sets more particularly. Whatever may be the validity of this explanation, the circumstance is an interesting one and well worthy of attention.*

485. The *general homology* of the Cephalic nerves, considered with reference to the ordinary Spinal, constitutes a study of much interest. It appears, from what has been already stated, that the Pneumogastric, Spinal Accessory, Glosso-pharyngeal, and Hypoglossal nerves, may be considered nearly in the light of ordinary Spinal nerves. They all take their origin exclusively in the Medulla Oblongata; and the want of correspondence in position between their roots and those of the Spinal nerves, is readily accounted-for, by the alteration in the direction of the columns of the Spinal cord, which not only decussate laterally, but, as it were, antero-posteriorly (§ 475). The Hypoglossal, as just stated, not unfrequently possesses a sensory in addition to its motor root. The Glosso-pharyngeal, which is principally an afferent nerve, has a small motor root; but most of the motor fibres which answer to it are to be found in the Pneumogastric. That the Pneumogastric and Spinal Accessory together represent a Spinal nerve, may be regarded as probable from what has been already said of their relations.—Leaving these nerves out of the question, therefore, we proceed to the rest. Comparative anatomy, and the study of Embryonic development, alike show that the Spinal Cord and Medulla Oblongata constitute the most essential part of the nervous system in Vertebrata; and that the Cerebral Hemispheres are superadded, as it were, to this. At an early period of development, the Encephalon consists chiefly of four vesicles, which correspond with the ganglionic enlargements of the nervous cord of the Articulata, and mark four

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* It may be questioned, however, whether the Hypoglossal is really paralyzed on the opposite side from the Facial in such cases. An instance has been communicated to the Author by Dr. W. Budd, in which the hypoglossal nerve was completely divided on one side; and yet the tip of the tongue, when the patient was desired to put it out, was sometimes directed *from* and sometimes *towards* the palsied side; showing that the muscles of either half are sufficient to give any required direction to the whole.

divisions of the Cerebro-Spinal axis; and, in accordance with this view, the Osteologist is able to trace, in the bones of the cranium, elements which present an analogy to those that would form four vertebræ, in a much expanded and altered condition. The four pairs of nerves of special sensation,—Auditory, Gustatory, Optic, and Olfactory,—make their way out *through* these four cranial vertebræ respectively. At a later period of development other nerves are interposed *between* these; which, being *intervertebral*, are evidently more analogous to the Spinal nerves, both in situation and function. A separation of the primitive fibres of these takes place, however, during the progress of development, so that their distribution appears irregular. Thus the greater part of the sensory fibres are contained in the large division of the Trigeminus; whilst of the motor fibres, the anterior set chiefly pass forwards as the Oculo-motor and Patheticus; and of the posterior, some form the small division of the Trigeminus, and others unite with the first pair from the Medulla Oblongata to form the Facial. This last fact explains the close union which is found in Fishes and some Amphibia, between that nerve and those proceeding more directly from the Medulla Oblongata. According to Valentin, the Glosso-pharyngeal is the sensory portion of the first pair from the Medulla Oblongata, of which the motor part is chiefly comprehended in the Facial nerve. Although we are accustomed to consider the Fifth pair as *par éminence* the Spinal nerve of the head, the foregoing statements, founded upon the history of development,* show that the nerves of the Orbit really belong to its motor portion; they may consequently be regarded as altogether forming the *first* of the *intervertebral* nerves of the cranium. The Facial and Glosso-pharyngeal appear to constitute the *second;* whilst the Par Vagum and Spinal Accessory, forming the *third* pair, intervene between this and the true Spinal, of which the Hypoglossal may be considered as the first.

486. *Functions of the Spinal Axis.*—In considering the functions of the Spinal Cord, we have to regard it under two aspects;—in the first place, as a *conductor* of nervous force between the Nerve-trunks and the Encephalic centres;—and in the second place, as itself *an independent centre* of nervous power. As a mere conductor of nervous force, its functions are the same as those of a nerve-trunk;† for if it be divided, all the parts of the body which are solely supplied by nerves coming-off below the point of section are completely paralyzed, as far as regards sensibility and voluntary movement; no impressions made upon them having the least power to affect the consciousness, and no exertion of the will being able to determine contraction of their muscles. This state of *paraplegia*, which may be experimentally induced in animals, is frequently exhibited in Man as a result of injury or of disease which seriously implicates the Spinal Cord; and as it has been shown that among the lower animals complete reunion of the Cord may take place after complete division, as indicated by the entire restoration of its functional powers and the com-

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* On this point, as well as on the functions of the Cephalic nerves generally, see Prof. Valentin, "De Functionibus Nervorum Cerebralium et Nervi Sympathici," Bernæ, 1839.

† Valentin ("Die Zuckungsgesetze des lebenden Nerven und Muskels," 1863, p. 86) observes that the whole Spinal Cord behaves like a large nerve on applying electrical stimulation to it, though its irritability is very rapidly exhausted.

plete redintegration of its structure,* so have we reason to believe that a similar regeneration may take place to a considerable extent in Man, this being marked by the gradual return of sensibility and power of voluntary movement in the lower limbs which had been at first completely paralyzed. This regeneration is of course less likely to occur in cases of disease, when the parts around are in an unhealthy state, than when the paralysis is due to injury, which all the restorative powers of the system are engaged in repairing; but it is to be remembered, that as the injuries which are likely to cause such lesions of the Cord are nearly always attended with severe concussion (it being very rare for the Cord to be accidentally wounded by the penetration of a sharp instrument between the vertebræ, in the mode in which experiments are made upon animals), some of their first effects are attributable to the *shock* which it has sustained; so that the partial recovery which takes-place at an early period, must not be regarded as the result of regeneration of nervous tissue, which requires a much longer time for its completion.—The conducting power of the entire Spinal Cord being thus established, we have next to inquire whether any difference in endowment can be shown to exist in its several columns.

487. *The Spinal Cord considered as a Conductor of Sensory Impressions.*—The accuracy of the description given by Mr. Lockhart Clarke (§ 469) of the course pursued by the fibres of the posterior roots of the Spinal nerves, has been materially corroborated by the experiments of M. Brown-Séquard† and many other physiologists. Considerable differences of opinion, however, still exist on various points, which require to be cleared-up by future investigation. According to M. Brown-Séquard, all the fibres of the posterior roots, either immediately or after a short ascending or descending course, cross the median line, and enter the grey substance of the opposite side, in which they ascend to the Medulla Oblongata (see *p r*, Fig. 120). As a consequence of this, if a section be made through one half of the Cord (as at 3), it follows that whilst the sensibility of that side of the body which corresponds to the section will remain perfect, that of the opposite side, will be wholly destroyed; or if, as occasionally happens, some indications of sensibility still persist, they are attributable only to the pain occasioned by reflex muscular convulsions on that side.‡ And again, it is obvious that if a longitudinal section of the Cord be made, dividing it into two lateral halves, sensibility will be totally extinguished on both sides of the body; for such a section would obviously divide all the sensory nerves entering the Cord, as they all decussate in the median line. According to M. Brown-Séquard, this is actually the result obtained. Other observers, however, as Oré,§ Longet,‖ and Schiff,¶ though admitting there is great diminution of sensibility after a longitudinal division of the Cord, yet maintain that distinct evidence of the conduction of sensory impressions may still be obtained; and it seems probable from their experiments, that

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[*] See the admirable researches of M. Brown-Séquard, in "Gazette Médicale," 1849, No. 45, and 1850, No. 30; also the "Comptes Rendus de la Société de Biologie," 1849, 1850.

[†] "Central Nervous System," 1860.

[‡] Op. cit., p. 35.

[§] "Comptes Rendus," tom. xxxviii. 1854, p. 930; "Comptes Rendus de la Société de Biologie," v. p. 302.

[‖] "Physiologie," 1860, vol. ii. p. 373.

[¶] "Physiologie," 1859, p. 274.

some few fibres may ascend in the grey substance, or in the posterior white columns of their own side. Perhaps the discrepancies in the results of the operation are due to different animals having been employed for experiment; for M. Brown-Séquard has himself observed that the decussation of the sensory fibres is neither so complete nor immediate in Reptiles and Birds as in Mammals, and that it does not seem to be so perfect in the lumbar as in the dorsal region.* There can be little doubt that the grey substance is essentially the channel through which sensory impressions are conducted upwards; for if the anterior, posterior, and antero-lateral columns are divided as completely as possible, the grey substance remaining uninjured, the sensibility of the parts below the section continues perfect, or nearly so;† whilst, however carefully the white columns are preserved from injury, if the grey substance be divided, sensibility is almost totally extinguished. It is remarkable, however, that the smallest longitudinal column or transverse layer of the grey substance remaining perfect may serve, to a certain limited extent, as the means of conduction for either side. The central portions of the grey substance are, as M. Brown-Séquard has shown, the most effective in the transmission of sensations; much more so, at all events, than either the anterior or posterior cornua. The circumstance that if the posterior white columns be divided, the surface of the caudal segment of the cord is as sensitive or even more sensitive than that of the cephalic segment, is explained by M. Brown-Séquard on the ground that some of the sensory fibres of the posterior roots descend for a little way in these columns before crossing to the opposite side; whilst Schiff appears to consider that it is attributable to the power he believes the grey substance (some of which must always be exposed in such sections) to possess of conducting in any direction, laterally as well as longitudinally. M. Brown-Séquard has, however, adduced very strong evidence in favour of there being fixed channels for the conduction of sensory impressions, the presence of some of which cannot compensate for the absence of others; indeed, he maintains that there are special conductors in the Spinal Cord for the sensations of touch, pain, temperature, and muscular contraction, none of which can convey other sensations than their own. Notwithstanding its singular power of conducting sensory impressions, numerous experiments have shown that the grey substance of the Spinal Cord is itself insensible; a peculiarity which Schiff‡ has expressed by terming it the 'æsthesodic'§ substance. The slight amount of sensibility which persists when the grey substance is wholly destroyed at any point, may perhaps be due, as Schiff ‖ maintains, to the passage of some sensory fibres in the posterior columns; though, if this be true, they only conduct the fibres belonging to their own side of the body: or it may be

FIG. 120.

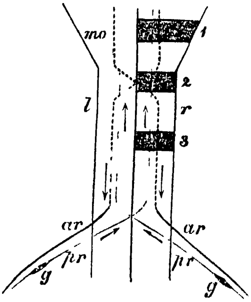

Diagram showing the course of Motor and Sensory Fibres in the Spinal Cord and Medulla Oblongata.

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* Op. cit., p. 37.

† Schiff, Op. cit., p. 241.

‡ Op. cit., p. 247.

§ From αἴσθησις, sensation, and ὁδὸς, a path.

‖ Op. cit., p. 252.

due, as M. Brown-Séquard maintains,* to the passage of a few fibres in the anterior and antero-lateral white columns, derived from the opposite side of the body.—A very remarkable result of section of one half of the Spinal Cord is that, besides the anæsthesia which is established on the opposite side of the body, there is produced a state of exalted sensibility or hyperæsthesia on the same side.† This condition, made apparent by the cries of the animal on the slightest pricking or pinching of the skin, begins to appear a few hours after the operation, rapidly attains its full intensity, and continues to be well marked for from 17 to 22 days in dogs, and from 12 to 16 days in cats; after which, according to Schiff,‡ it gradually decreases, until at length the sensibility falls below its normal acuteness. M. Brown-Séquard has however observed it to persist in guinea-pigs, though not in a very high degree of intensity, for many months after the operation. The cause of this phenomenon has not been accurately determined. It is certainly accompanied by an increased flow of blood and increased temperature of the parts to which the nerves are distributed, and hence M. Brown-Séquard seems to regard it as having a peripheric origin; whilst Schiff considers it rather as the result of irritation (as from the inflammatory process) occurring at the seat of injury: the latter view is supported by the observation of Chauveau, that it will sometimes ensue in cases when the vertebral canal has merely been opened, apparently as a consequence of the exposure and pressure of the Cord against the edges of the wound; and also by that of Türck, that hyperæsthesia may sometimes be observed in frogs on the same side of the body *above* the section. Hyperæsthesia may also be produced by section of the anterior or posterior columns alone.§

488. *The Cord as a Conductor of Motor Impulses.*—However difficult it may be to determine the exact channels by which sensory impressions are conveyed through the Spinal Cord, the present inquiry seems to be beset with still greater uncertainty. From the experiments of Brown-Séquard, it appears that the posterior white columns at least take no part in the transmission of such impulses; for if these be divided transversely in the dorsal region, no perceptible diminution of voluntary motion occurs; whilst if the whole Spinal Cord is divided with the exception of these columns, the power of voluntary movement appears to be completely abolished. The results obtained by various experimenters show that the anterior and antero-lateral columns contain motor tracts, as was originally held by Sir Charles Bell; for if all the grey substance and the posterior columns be divided, the animal can still perform voluntary movements; whilst if at a higher level the anterior columns alone be also severed, leaving the remaining portions of the Cord untouched, movement is wholly lost. If, however, in the lower section the anterior cornua of the grey substance be left, and the section above be again made only through the white anterior columns, movements can still be spontaneously executed.‖ Considerable differences, however, undoubtedly exist in the position of the motor tracts in different parts of the Spinal Cord; and M. Brown-Séquard¶ concludes from his numerous experiments on the effects of section, that whilst, in the *dorsal region*, all parts of the Spinal Cord except the poste-

* Op. cit., p. 23.

† See Brown-Séquard, "Central Nervous System," 1860, p. 19.

‡ Op. cit., p. 275.

§ Schiff, Op. cit., p. 274.

‖ Schiff, Op. cit., p. 283.

¶ Op. cit., p. 46.

rior columns are employed in the conveyance of the orders of the Will to the muscles, in the upper part of the *cervical* region most of these conductors are in the lateral columns, and in the grey substance between these and the anterior columns, the latter here having little share in the transmission of such impulses. The same observer has satisfactorily shown that the fibres which transmit motor impulses decussate almost exclusively at the lower part of the Medulla Oblongata. (See *a r*, Fig. 120.) Hence, if a section of one-half of the Spinal Cord be made (as at 3, Fig. 120), loss of movement on the *same side* occurs, in consequence of the division of the ascending motor fibres (*a r*) from the anterior roots; whilst if the section be made at the level of the decussation of the anterior pyramids (as at 2), paralysis of the muscles of both sides is produced; lastly, if a section be made a little higher (as at 1), paralysis of the muscles of the opposite side results. Numerous fibres belonging to the anterior roots undoubtedly decussate throughout the greater part of the Spinal Cord; but these are probably destined, as suggested by Brown-Séquard, to be channels for the conveyance of reflex actions. Schiff proposes the term "kinesodic[*] substance" for the material by which motor impulses are conveyed along the Spinal Cord, on the ground that when directly stimulated the movements performed are few and imperfect; and he appears to think that as with the "asthesodic substance," so with the "kinesodic substance," the smallest portion is capable of transmitting motor impulses in any direction. M. A. Chauveau appears to agree with Schiff in this respect: for he observes[†] that under ordinary circumstances neither motion nor sensation can be produced (except in one or two points) by direct stimulation of the Spinal Cord; that the antero-lateral columns are quite inexcitable, both on their surface and in their deeper parts, whether composed of white or grey substance; that the posterior columns, on the contrary, are very sensitive on their surface, but, like the former, do not respond to impressions made in their substance; that by their reaction upon direct irritation, pain and reflex movements are produced when the Cord is in connection with the Brain, but as reflex movements alone when the Cord is divided; that *reflex* movements are the only movements that can be produced by direct irritation of the substance of the Cord, since the irritation is not limited to special muscles, but appears to be propagated as a motor impulse both upwards and downwards through the Spinal Cord, so as to implicate muscles above and below the parts irritated; and lastly, he observes that it is incorrect to speak of an anterior motor and posterior sensory part of the Cord, since these properties are not localized in special tracts. The researches of Van Deen[‡] led on the whole to the same conclusions; and tended, in his opinion, to show that the conducting power both of the anterior and posterior columns was very imperfect, if their white strands were completely separated from their grey matter. His experiments conclusively established that the grey matter, as well as the white, possessed conducting powers; additional evidence of which is derived from the circumstance, that it contains a large amount of the fibrous form of nerve-tissue, and that the commissural connection between the two lateral halves of the Cord is established (according to Mr. J. L. Clarke) by its grey substance alone.

[*] From κίνησις, motion, and ὁδὸς, a path.

[†] Brown-Séquard's "Journ. de la Physiol.," 1861, tom. iv. p. 369.

[‡] "Traités and Découvertes sur la Physiologie et la Moëlle Epinière," Leide, 1841.

489. We have now to consider the Spinal Cord *as an independent centre* of nervous power, and to inquire whether the movements which are excited through its 'reflex' activity necessarily involve sensation. These movements are most characteristically displayed, when the Spinal Cord is cut-off from communication with the higher Nervous centres; probably rather because the nerve-force excited by the impression reacts through the Spinal ganglion to which it is conveyed, when it can no longer pass-on to the Encephalic centres (§ 440), than because (as some suppose) the impulse to reflex movement is ordinarily neutralized and rendered inoperative by an effort of the Will. It is true that those reflex actions of the Spinal Cord which are necessary to the maintenance of Organic life, and which are equally performed whether the Spinal axis be in communication with the higher Encephalic centres or not, are continually modified or temporarily suspended by the Will; but this is only when we consciously bring the Will to bear upon them; and it is no less certain that we are *not* continually making any such exertions, in order to antagonize movements, which (as we learn from Pathological evidence*) would be continually excited but for this neutralizing influence, if such a doctrine were correct.—The readiest demonstration of the independent power of the Spinal Cord, is derived from the motions exhibited by the limbs of animals, when irritation is applied to them after section of the Spinal Cord at some point above the entrance of their nerves; the fact that these movements are reflected through the Cord, and are not the product of direct stimulation applied to the part irritated, being shown by their complete cessation when the nerve-trunks are divided, or the substance of the Spinal Cord is broken-down. Thus, if a frog be decapitated, its body remains supported on its limbs in the usual position, and will recover this if it be disturbed; irritation of the feet will cause it to leap; and tickling the cloaca with a probe will excite efforts to push away the instrument.†

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* See, for example, the case of 'Softening of the Spinal Marrow,' recorded by Dr. Nairne in the "Med.-Chir. Trans.," vol. xxxiv.; in which a portion of the Cord at least an inch long, situated opposite the third and fourth dorsal vertebræ, was "so soft that the slightest pressure of the finger broke it up," being nearly in a fluid state through its whole thickness; yet the patient felt *pain* in his lower limbs, showing that the power of *upward* transmission remained; and although he had lost all Voluntary control over the muscles of the lower part of the body, yet they were affected with incessant *choreic* movement (which, as will be shown hereafter, Sect. 8, appears to originate in the Sensory Ganglia), and these movements were affected in such a marked manner by *emotions*, as plainly to indicate a *downward* transmission of motor power.

† It has been pointed-out by Messrs. Todd and Bowman ("Physiological Anatomy," vol. i. p. 315), that the Spinal Cord of the male frog, at the season of copulation, naturally possesses a state of most extraordinary excitability. The thumb of each anterior extremity at this season becomes considerably enlarged; as is well known to Naturalists. "This enlargement is caused principally by a considerable development of the papillary structure of the skin which covers it; so that large papillæ are formed all over it. A male frog, at this season, has an irresistible propensity to cling to any object, by seizing it between his anterior extremities. It is in this way that he seizes-upon, and clings-to the female; fixing his thumbs to each side of her abdomen, and remaining there for weeks, until the ova have been completely expelled. An effort of the Will alone could not keep up the grasp uninterruptedly for so long a time; yet so firm is the hold, that it can with difficulty be relaxed. Whatever is brought in the way of the thumbs, will be caught by the forcible contraction of the anterior limbs; and hence we often find frogs clinging blindly to a piece of wood, or a dead fish, or some other substance which they may chance to meet with. If the finger be placed between the anterior extremities, they will grasp it firmly; nor will they relax their grasp until they are separated by force. If the animal be decapitated whilst the finger is within the grasp of its anterior extremities, they still continue

It is to be observed that a slight irritation applied to the peripheral *extremities* of the afferent nerves, is a more powerful excitor of reflex action, than a much stronger impression, which occasions acute pain, applied to their *trunks;* thus Mr. Grainger found that he could remove the entire hind leg of a Salamander with the scissors, without the creature moving, or giving any expression of suffering, if the Spinal Cord had been first divided; yet that by irritation of the foot, especially by heat, in an animal similarly circumstanced, violent convulsive actions were excited in the legs and tail. This fact is important, not only as showing the comparatively-powerful effect of impressions upon the cutaneous surface, but also as proving how little relation the amount of reflex action has to the intensity of sensation.

490. That the movements executed by the limbs of the lower animals, when these are no longer connected by the Spinal Cord with the Encephalon, but remain in nervous connection with the Cord itself, do not take place through the intermediation of sensation, might be supposed to be sufficiently proved by the simple fact, that division of the Cord in Man, and hence by inference in the lower animals, reduces the parts below to a state of complete insensibility. But, on the other hand, the very performance, by decapitated animals of inferior tribes, of actions which had not been witnessed in Man under similar circumstances, has been held to indicate, that the Spinal Cord in them has an endowment which *his* does not possess. The possibility of such an explanation, however unconformable to that analogy throughout organized nature, which, the more it is studied, the more invariably is found to guide to truth, could not be disproved. Whatever experiments on decapitated animals were appealed-to, in support of the doctrine that the Encephalon contains the only seat of sensibility, could be met by a simple denial that the Spinal Cord is everywhere as destitute of that endowment as it appears to be in Man. The cases of profound Sleep and Apoplexy might be cited as examples of reflex action without consciousness; but these have been met by the assertion, that in such conditions, sensations are *felt*, though they are not *remembered.* It is difficult, however, to apply such an explanation to the case of Anencephalous human infants (in which all the ordinary reflex actions have been exhibited, with an entire absence of brain), without supposing that the Medulla Oblongata is the seat of a sensibility which we know that the lower part of the Spinal Cord does not possess; and of this there is no evidence whatever.—Experiments on the lower animals, then, and observation of the phenomena manifested by apoplectic patients and anencephalous infants, *might* lead to the conclusion, that the Spinal Cord does not itself possess sensibility, and that its reflex actions are independent of sensation. At this conclusion, Unzer, Prochaska, Sir G. Blane, Flourens, and other physiologists had arrived; but it was not until special attention was directed to the subject by Dr. M. Hall, that facts were obtained by which a positive statement of it could

to hold-on firmly. The posterior half of the body may be cut away, and yet the anterior extremities will still cling to the finger; but immediately that the segment of the Cord, from which the anterior extremities derive their nerves, has been removed, all their motion ceases. This curious instinct only exists during the period of sexual excitement; for at other periods the excitability of the anterior extremities is considerably less than that of the posterior."

be supported. For the question might have been continually asked,—It the Spinal Cord in Man be precisely analogous in function to that of the lower Vertebrata, why are not *its* reflex phenomena manifested, when a portion of it is severed from the rest by disease or injury? The answer to this question is twofold. In the first place, simple division of the cord with a sharp instrument leaves the separated portion in a state of much more complete integrity, and therefore in a state much more fit for the performance of its peculiar functions, than it ordinarily is after disease or violent injury; and as the former method of division is one with which the Physiologist is not likely to meet in Man as a result of accident, and which he cannot experimentally put in practice, the cases in which reflex actions would be manifested are likely to be comparatively few. But, secondly, a sufficient number of such instances *have* now been accumulated, to prove that the occurrence is by no means so rare as might have been supposed; and that nothing is required but patient observation, to throw a great light on this interesting question from the phenomena of disease. A most valuable collection of such cases, occurring within his own experience, has been published by Dr. W. Budd;* and the leading facts observed by him will be now enumerated.

491. In the first case, Paraplegia was the result of angular distortion of the spine in the dorsal region. The sensibility of the lower extremities was extremely feeble, and the power of voluntary motion was almost entirely lost. "When, however, any part of the skin is pinched or pricked, the limb that is thus acted-on jumps with great vivacity; the toes are retracted towards the instep, the foot is raised on the heel, and the knee so flexed as to raise it off the bed; the limb is maintained in this state of tension for several seconds after the withdrawal of the stimulus, and then becomes suddenly relaxed." "In general, while one leg was convulsed, its fellow remained quiet, unless stimulus was applied to both at once." "In these instances, the pricking and pinching were perceived by the patient; but *much more violent* contractions are excited by a stimulus, of *whose presence he is unconscious.* When a feather is passed lightly over the skin, in the hollow of the instep, as if to tickle, convulsions occur in the corresponding limb, much more vigorous than those induced by pinching or pricking; they succeed one another in a rapid series of jerks, which are repeated as long as the stimulus is maintained." "When any other part of the limb is irritated in the same way, the convulsions which ensue are very feeble, and much less powerful than those induced by pricking or pinching." "Convulsions, identical with those already described, are at all times excited by the acts of defecation and micturition. At these times, the convulsions are much more vigorous than under any other circumstances, insomuch that the patient has been obliged to resort to mechanical means to secure his person while engaged in these acts. During the act of expulsion, the convulsions succeed one another rapidly, the urine is discharged in interrupted jets, and the passage of the fæces suffers a like interruption." The convulsions are more vigorous, the greater the accumulation of urine; and involuntary contractions occur whenever the bladder is distended, and also when the desire to relieve the rectum is manifested. "In all these circumstances,

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* "Medico-Chirurgical Transactions," vol. xxii.

the convulsions are perfectly involuntary; and he is unable, by any effort of the will, to control or moderate them." This patient subsequently regained, in a gradual manner, both the sensibility of the lower extremities, and voluntary power over them; and as voluntary power increased, the susceptibility to involuntary movements diminished, as did also their extent and power.—This case, then, exhibits an increased tendency to perform reflex actions, when the control of the Brain was removed; and it also shows that a slight impression upon the *surface*, of which the patient was not conscious, was more efficacious in exciting reflex movements, than were others that more powerfully affected the sensory organs. —It should be added that, in the foregoing case, the nutrition of the lower extremities was not impaired, as it is in most cases of paraplegia; the rationale of this phenomenon, which is to be constantly observed when the reflex actions of the part remain entire, will be understood by reference to §§ 342, 500.

492. In another case, the paralysis was more extensive, having been produced by an injury (resulting from a fall into the hold of a vessel) at the lower part of the neck. There was at first a total loss of voluntary power over the lower extremities, trunk, and hands; slight remaining voluntary power in the wrists, rather more in the elbows, and still more in the shoulders. The intercostal muscles did not participate in the movements of respiration. The sensibility of the hands and feet was greatly impaired. There were retention of urine, and involuntary evacuation of the fæces. Recovery took place very gradually; and during its progress, several remarkable phenomena of reflex action were observed. At first, tickling one sole excited to movement that limb only which was acted-upon; afterwards, tickling either sole excited both legs, and, on the 26th day, not only the lower extremities, but the trunk and upper extremities also. Irritating the soles, by tickling or otherwise, was at first the only method, and always the most efficient one, by which convulsions could be excited. From the 26th to the 69th day, involuntary movements in all the palsied parts continued powerful and extensive, and were excited by the following causes: in the lower extremities only, by the passage of flatus from the bowels, or by the contact of a cold urinal with the penis; convulsions in the upper extremities and trunk, attended with sighing, by plucking the hair of the pubes. On the 41st day, a hot plate of metal was applied to the soles, and was found to be a more powerful excitor of movement than any before tried. The movements continued as long as the hot plate was kept applied; but the same plate, at the common temperature, excited no movements after the first contact. Though the contact was distinctly felt by the patient, *no sensation of heat* was perceived by him, even when the plate was applied hot enough to cause vesication. At three different intervals, the patient took one-eighth of a grain of strychnia three times a day. Great increase of susceptibility to involuntary movements immediately followed, and they were excited by the slightest causes. No convulsions of the upper extremities could ever be produced, however, by irritating their integument; though, under the influence of strychnia, pulling the hair of the head or tickling the chin would occasion violent spasmodic actions in them. Spontaneous convulsions of the palsied parts, which occurred at other times, were more frequent and more powerful after the use of strychnia.

On the first return of voluntary power, the patient was enabled to restrain in some measure the excited movements; but this required a distinct effort of the will; and his first attempts to walk were curiously affected by the persistence of the susceptibility to excited involuntary movements. When he first attempted to stand, the knees immediately became forcibly bent under him; this action of the legs being excited by contact of the soles with the ground. On the 95th day this effect did not take place until the patient had made a few steps; the legs then had a tendency to bend-up, a movement which he counteracted by rubbing the surface of the belly; this rubbing excited the extensors to action, and the legs became extended with a jerk. A few more steps were then made, the manœuvre was repeated, and so on. This susceptibility to involuntary movements from impressions on the soles gradually diminished; and on the 141st day the patient was able to walk about, supporting himself on the back of a chair which he pushed before him; but his gait was unsteady, and much resembled that of chorea. Sensation improved very slowly: it was on the 53rd day that he first slightly perceived the heat of the metal plate.—Now in this case, the abolition of common sensation was not so complete as in the former instance; but of the peculiar kind of impression which was found most efficacious in exciting reflex movements, *no consciousness whatever was experienced.* Not less interesting was the circumstance, that convulsions could be readily excited by impressions on surfaces *above* the seat of injury: as, by pulling the hair of the scalp, a sudden noise, and so on. This proves two important points: first, that a lesion of the Cord may be such as to intercept the transmission of voluntary influence, and yet may allow the transmission of that reflected from incident nerves. Secondly, that all influences from impressions on incident nerves are diffused through the Cord; for, in the instance adduced, the reflected influence was undoubtedly not made to deviate into the cord by the morbid condition of that organ, but followed its natural course of diffusion, being rendered manifest in this case by the convulsions which were excited, in consequence of increased activity of the motor function of the cord. It is further interesting to remark, that, in the foregoing case, the reflex actions were very feeble during the first seven days, in comparison with their subsequent energy; being limited to slight movements of the feet, which could not always be excited by tickling the soles. (In another case of very similar character, it was three days after the accident, before any reflex actions could be produced.) It is evident, then, that the Spinal Cord must have been in a state of concussion, which prevented the manifestation of its peculiar functions, so long as this effect lasted; and it is easy, therefore, to perceive, that a still more severe shock might permanently destroy its power, so as to prevent the exhibition of any of the phenomena of reflex action.

493. So many cases of this kind have now occurred, that it may be considered as a demonstrated fact, that the Spinal Cord, or insulated portions of it, may serve in Man, no less than in the lower animals, as the centre of very energetic reflex actions, when the Encephalic power which ordinarily operates through it is suspended or destroyed, or when it is prevented from influencing the Spinal nerves by such an injury to the Cord above their points of connection with it, as prevents the trans-

mission of nervous polarity: and it is further evident that these movements are not more dependent upon Sensation than they are upon the Will, since they may be excited without the consciousness of the individual, even when this is fully directed to the part.* And we thus have adequate ground for the assertion, that the movements which may be called-forth by stimulation in the states of profound Sleep or Coma, are not to be held to indicate that conscious sensation is even momentarily excited; since we know that the reflex power of the Spinal Cord may be called into action by impressions which do not travel onwards to the sensorium, or which are powerless to affect the consciousness even when they arrive there. These abnormal reflex actions of the Spinal Cord of Man, though often powerful, have much less regularity and apparent *purposiveness*, than have the movements executed by the lower Vertebrata (as the Frog, § 489) after decapitation or section of the cord; the latter approaching, in respect to these qualities, to the reflex movements of Articulated animals—as is well seen in the following experiment, which is much relied on by those who hold that the Spinal Cord is the seat of sensorial functions.† If a frog be decapitated and acetic acid be applied over the internal condyle of the femur, the animal will wipe away the acid with the foot of the same side; but if this be cut off, after some ineffectual efforts and a short period of hesitation, it will perform the same action with the foot of the opposite side. It must not hence be inferred, however, that there is any essential difference in the endowments of the Spinal Cord, between Man and the lower animals; or that any *psychical* agency exists in the latter case, which is wanting in the former. We have already seen that the existence of even the most perfectly-adapted combination of different muscular actions, all obviously bearing upon a definite object, cannot in itself justify our attributing this combination to design or voluntary choice on the part of the organism that executes it (§ 430); whilst, on the other hand, to remove these movements in any case from the category of *automatic* actions, would be to assign to the Spinal Cord a power of consciously selecting and directing them, such as we have every reason for believing to be limited to the higher parts of the Cerebro-Spinal centres. Now the very *uniformity* of the movements in question, or the slight variation in effect which has been observed to follow the application of different stimuli, is itself an indication that they do *not* proceed from any purposive choice, but depend upon the special endowments of those centres of reflex action, whence the impulses that call them forth immediately issue to the nerves:

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* The Author is informed by his friend Mr. Paget, that among the notes left by John Hunter (which furnished some of the materials for the admirable Catalogue of the Pathological portion of the Hunterian Museum drawn-up by Mr. Paget), there was the record of a case of paraplegia, in which it appeared that Hunter had witnessed reflex movements of the legs in which sensation did not participate. When the patient was asked whether *he felt* the irritation by which the motions were excited, he significantly replied—glancing at his limbs,—"No, Sir; but you see *my legs* do."

† See Pfluger, "Die sensorischen Functionen des Rückenmarks," Berlin, 1853; see also an able review in the "Med.-Chir. Review" for Jan. 1864, in which the above experiment is quoted. The doctrine of the independent volitional as well as sensorial power of the Spinal Cord is ingeniously sustained in Mr. G. H. Lewes's "Physiology of Common Life," vol. ii.; whilst the opposite side is taken in a review upon that work contained in the "Med.-Chir. Review," vol. xxvi., 1860, p. 423.

and hence the more marked adaptiveness of the reflex actions performed by many of the lower tribes of animals, can only be held to indicate that a larger share of such adaptation is effected in them by what may be termed the *mechanism* of their nervous centres, and that less is left to voluntary choice and direction, which can only be safely trusted where a considerable amount of intelligence exists to guide it;—a conclusion which accords well with what has been already stated, respecting the structural differences that seem to exist between the Spinal Cord of Man, and that of the inferior Vertebrata (§ 473). A peculiar condition described by Schiff* as Analgesia may here be alluded-to. It consists in the retention of the capability of perceiving sensations of *touch*, though the most severe injuries to nerves produce no sensations of *pain*. This condition may be induced, according to Schiff, by division of the whole Spinal Cord with the exception of the posterior columns, also by rapid abstraction of blood; and it may be observed in the early stages of the administration of ether or chloroform. It seems to be questionable, however, whether this is not rather to be considered as a state of blunted common sensibility.

494. The endowments of the *Medulla Oblongata* do not seem to differ from those of the Spinal Cord in any other respect, than in the speciality of the reflex movements to which it ministers. This part of the Cranio-Spinal Axis has been regarded by some Physiologists, indeed, as the peculiar seat of vitality; since, although the other Encephalic masses may be withdrawn from above, and nearly the whole of the Spinal Cord may be removed from below, without the destruction of life, yet a complete stop is put to the current of vital action when the Medulla Oblongata is destroyed. But the dependence of the vital activity of the body generally upon the functional integrity of this part of the nervous system, is simply consequent upon the fact that the Medulla Oblongata contains the chief ganglionic centre of the Respiratory movements;† upon the continuance of which, as already shown (CHAP. VII. Sect. 3), the continuance of the Circulation is dependent, and with this, the maintenance of the Organic functions generally. A strong confirmation of this is found in the fact that M. Brown-Séquard‡ has kept frogs, in which animals the cutaneous respiration is actively performed, alive for eight months after the entire removal of the Medulla Oblongata. From the Medulla Oblongata spring the nerves which exert a regulatory or inhibitory power on the movements of the heart (§ 216), and also those which are intimately associated with the formation of sugar in the liver (§ 381). It is also the ganglionic centre of the nerves of Speech and Deglutition; the abolition of which latter function must of course be destructive to life, though less speedily than that of Respiration. As regards the functions of the several strands composing the Medulla Oblongata, little is known, excepting that the anterior pyramids are the conductors for voluntary motor impulses, whilst the Corpora Restiformia, which constitute the inferior peduncles of the Cerebellum, do not appear, according to M. Brown-Séquard,§ to give passage to any of the conductors of *sensory* impressions proceeding from the trunk, limbs, or head. It is remarkable, however, that

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* "Physiologie," 1859, p. 252.

† Brown-Séquard considers that the whole base of the Encephalon in Man is implicated in Respiration ("Central Nervous System," p. 191).

‡ "Central Nervous System," 1860, p. 191.

§ Ibid., p. 27.

after they have been transversely divided, hyperæsthesia is produced in every part of the trunk and limbs.

495. Hence the Spinal Cord, with its Encephalic prolongation, may be said to supply by its 'reflex power' *the conditions requisite for the maintenance of the various muscular movements which are essential to the continuance of the Organic processes;* and, as Dr. M. Hall has pointed-out, it especially governs the various orifices of ingress and egress.—Thus, the act of Deglutition is entirely dependent upon the Spinal Axis and the nerves proceeding from it; the Will being in no other way concerned in it, than by originating the necessary stimulus; and even sensation not being a necessary link in the chain of excito-motor action (§§ 68-70). The action of the cardiac sphincter, again,—and probably that of the pyloric sphincter also,—is dependent upon its nervous connection with the Spinal Axis; and is entirely regulated without sensorial excitement (§ 70). And there is much reason to believe that certain of the movements of the Stomach itself are in like manner dependent upon its connection with the Medulla Oblongata (§ 72), although there is evidence that it possesses an independent motor activity of its own. The movements of the Intestinal tube are unquestionably influenced by the Spinal Cord, although in great measure independent of it (§§ 74, 75); and the sphincter which surrounds its orifice of egress is undoubtedly placed under its guardianship, although partly subjected (in Man) to the control of the Will. The same may be said of the *expulsor* muscles concerned in the act of Defecation; and of the expulsors and sphincter which effect and control the act of Urination (§ 76).—Looking, again, at the movements which are subservient to the Respiratory process, we find that all those which are essential to its regular maintenance are performed through the intermediation of the Spinal Axis alone; that the Will has only such a limited power over them as to bring them into harmony with its other requirements, as in the acts of vocalization and in extraordinary muscular exertions; and that the stimulus by which they are commonly maintained does not even affect the consciousness, the 'besoin de respirer' only becoming *sensible* when the respiratory process is being imperfectly performed (§§ 274-276). Not only are the ordinary respiratory movements performed through this channel, but the aperture of the Glottis is regulated by it, in everything that concerns the respiration; and either by its spasmodic closure against the entrance of unfit substances, or by the expulsor effort of coughing which is excited by them when they do find their way into the air-passages, these passages are kept free from solid, liquid, or gaseous particles, whose presence in them would be injurious.—In the expulsion of the Generative products, also, the reflex power of the Spinal Cord takes an important share. Budge* believes that he has discovered a genito-spinal centre (in rabbits) in that portion of the Spinal Cord which lies opposite the fourth lumbar vertebra; for on irritating this part, contractions of the rectum, bladder, and vasa deferentia occurred. The same effects are produced on irritating the ganglion of the Sympathetic nerve lying on the fifth lumbar vertebra, which receives communicating branches from this part of the cord; and the influence of the nervi erigentes and common

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* "Comptes Rendus de l'Acad. des Scien.," 1858, p. 586; and "Physiologie," 1862, p. 14.

pudendal nerves observed by Eckhard, on the erection of the penis and emissio seminis, has been already fully detailed (§ 255). The muscular contractions which produce Emissio Seminis are excito-motor in their nature; being independent of the Will, and not capable of restraint by it when once fully excited; and being (like those of Deglutition) excitable in no other way than by a particular local irritation. It has been shown by experiment, and also by pathological observation, that the separation of the lower portion of the Spinal Cord from the upper does not prevent these movements from being excited, although the act is then unaccompanied with sensation, which proves that sensation is not essential to its performance; on the other hand, the power of emission is annihilated by destruction of the lower portion of the Spinal Cord, or by section of the nerves which supply the genital organs. The act of Parturition, however, seems to be less dependent upon the Spinal Cord; for, as will be shown hereafter (CHAP. XVI., Sect. 3), the contractions of the Uterus, which are alone sufficient to expel the fœtus when there is no considerable resistance, are not to be regarded as 'reflex;' and it is only in the co-operation of those associated muscles which come into play in the second stage of labour, when the head is passing through the os uteri and is engaged in the pelvic cavity, that the assistance of the Spinal Cord and its nerves is called-in. These movements, like those of Defecation, may be to a certain extent promoted or restrained by voluntary effort; but when the exciting influence (the pressure of the head against the parietes of the vaginal canal) has once been fully brought into operation by the uterine contractions, the Will has little power over them, either in one way or the other. The antagonizing influence of the sphincter vaginæ seems, like that of the sphincter ani, to be dependent upon the Spinal Cord; and thus it happens that when its tension and that of other muscular parts has been destroyed by death, whilst the uterus still retains its contractility, the power of the latter has sufficed for the completion of the parturient process, the child being expelled after the respiratory movements have ceased.

496. The Spinal Axis is not merely the instrument whereby the movements essential to the maintenance of the Organic functions are sustained; it is also subservient to other muscular actions, whose character is essentially *protective*. Thus it was ascertained by Dr. M. Hall* that, if the functions of the Brain be suspended or destroyed without injury to the Spinal Cord and its nerves, the Orbicularis muscle will contract, so as to occasion the closure of the eyelids, upon their tarsal margin being touched with a feather. This fact is interesting in several points of view. In the first place, it is a characteristic example of an adaptive action, occurring under circumstances in which volition cannot be imagined to guide it, and in which there is no valid reason to believe that sensation directs it. Further, it explains the almost irresistible nature of the tendency to winking, which is performed at short intervals by the contraction of the Orbicularis muscle; this is evidently a reflex action, capable of being in some degree restrained (like that of respiration) by the will, but only until such time as the stimulus (resulting perhaps from the collection of minute particles of dust upon the eyes, or

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* "Memoirs on the Nervous System," 1837, p. 61.

from the dryness of their surface in consequence of evaporation,) becomes too strong to be any longer resisted. The nervous channel through which this action is performed, is completed by the first branch of the Fifth and the Portio Dura of the Seventh. Again, we have in sleep or in apoplexy an example of this purely-spinal action, unbalanced by the influence of the will, which, in the waking state, antagonizes it by calling the levator palpebræ into action. As soon as the will ceases to act, the lids droop, and close over the eye so as to protect it; and if those of a sleeping person be separated by the hand, they will be found presently to return. Here, as in studying the respiratory and other movements, we are led to perceive that it is the Brain alone which is torpid during sleep, and whose functions are affected by this torpidity. As Dr. M. Hall very justly remarks, "the Spinal system never sleeps;" it is constantly in activity; and it is thus that, in all periods and phases of Life, the movements which are essential to its continued maintenance are kept-up without sensible effort.—The closure of the pupil against a strong light, is another movement of the same protective tendency. The contraction of the pupil is immediately caused by the Third pair, or Motor Oculi, as is easily shown by irritating the trunk of that nerve and observing the result; but the stimulus which excites it is conveyed through the Optic nerve. Yet although the contraction of the pupil is usually in close accordance with the *sensation* occasioned by the impression of light upon the retina, yet there is evidence to prove that the sensation of light is not always necessary: for even when the sight of both eyes has been entirely destroyed by amaurosis, the normal actions have been witnessed in the pupil, in accordance with the varying degrees of light impinging on the retina. Such cases seem to indicate that the motion results from an *impression* upon the retina, which impression being conducted to the Sensorium ordinarily produces a sensation; but that even where no sensation is produced, on account of a disordered state of the part of the ganglionic centre in which the Optic nerve terminates, if the central tract which connects that nerve with the Third pair retain its integrity, the reflex contraction of the pupil may still be excited through it. The rarity of the occurrence is easily accounted-for, by the fact that in most cases of amaurosis the disease lies in the retina or in the trunk of the nerve, and thereby checks both its spinal and its encephalic actions. —Although we are not at present acquainted with any similar protective movements in the Human being, designed to keep the organ of Hearing from injury, yet there can be little doubt that those which we are constantly witnessing in other animals possessed of large external ears, are reflex actions excited by the irritation applied to them. In regard to the Nose, we find a remarkably complex action—that of Sneezing—adapted to drive-off any cause of irritation (§ 280). The stimulus is conveyed, in this case, not through the Olfactory nerve, but through the Fifth pair; so that it is not dependent upon the excitement of the sensation of Smell. The act of Coughing, also, may be regarded as of a protective character; being destined to remove sources of irritation from the air-passages. Many of the automatic movements performed by the limbs of Frogs and other animals, when their connection with the brain has been cut off (§ 489), appear destined to remove these parts from sources of irritation or injury; and they may thus be rightly placed under the same category.

497. The fact that Sensation is very commonly *associated with* the reflex actions we have been considering, being produced by the impression that excites them, has led many to suppose that it necessarily participates in them;—a doctrine which we have seen to be untenable. But the question not unnaturally arises, *why* Sensation should so constantly participate in these operations, if not essential to them; and the answer to this question is to be found in the fact, that it is only through sensation that a higher set of actions, mental and bodily, is called into play, which is essential to the *continued maintenance* of those belonging to the present category. Illustrations of this truth might be drawn from any of the functions already noticed; but the Ingestion of food will supply us with one of the most apposite. We have seen that the act of Deglutition is in itself independent of sensation; anything that comes within the grasp of the pharyngeal constrictors being conveyed downwards by their reflex contraction, just as anything which touches the arms of a Polype is entrapped by them and drawn into the stomach. But this action is attended with sensation, in the ordinary condition of the higher Animal, apparently in order that guidance may be thus afforded in the performance of those other movements of prehension, mastication, &c., by which the food may be brought within reach of the apparatus of deglutition; and the sensations which are linked with these are among the influences which prompt to those higher mental operations, whereby food is provided for the digestive apparatus to make use of. The Zoophyte is dependent for its supplies of aliment upon what the currents in the surrounding fluid, or other chances, may bring into its neighbourhood; and if these should fail, it starves. The anencephalous Infant, again, can swallow, and even suck; but it can execute no other movements adapted to obtain the supply of food continually necessary for its maintenance, because it has not a mind which sensations could awake into activity. The sensation connected with excito-motor actions has not only this important end, but it frequently contributes to enjoyment, as in Suction and Emissio seminis. The sensation accompanying the actions of this class, moreover, frequently affords premonition of danger, or gives excitement to supplementary actions destined to remove it, as in the case of Respiration; for where anything interferes with the due discharge of the function, the uneasy sensation that ensues, occasions unwonted movements, which are more or less adapted to remove the impediment, in proportion as they are guided by judgment as well as by consciousness. Again, sensation often gives warning against inconvenience, as in the Excretory functions; and here it is very evident, that its purpose is not only (if it be at all) to excite the associated muscles necessary for the excretion, but actually to make the Will set up the antagonizing action of the sphincters (§§ 76, 77).

498. We have now to inquire how far the independent action of the Spinal Cord is concerned in the general muscular movements of Man, and especially in the locomotive actions of his inferior extremities. On this point, it is obvious that we must not be guided by the analogy of the lower animals; since the locomotive and other movements of Man are for the most part volitional and purposive, and he has to acquire by experience that control over his muscular apparatus which is necessary to enable him to perform them; whilst in Invertebrata generally, and in

a large part of the lower Vertebrata, it is evident that the movements of progression, &c. which are characteristic of each species, come under the general category of automatic actions, and are provided-for in the original organization of its nervous centres, being performed without any education, and under circumstances which render the notion of a purpose on the Animal's own part quite untenable. In so far as these instinctive movements require the guidance and direction of sensations, they must be referred to the 'consensual' group; but clear evidence is afforded by the continuance of many of them after the removal of the centres of sensation, that they are excito-motor in their character, and that they require no higher centre than the ganglia which correspond to the Spinal Cord of Man.* There can be little doubt that the habitual movements of locomotion, and others which have become 'secondarily automatic,' may be performed by Man (under particular circumstances) through the agency of the Spinal Cord alone, under the guidance and direction of the Sensorial centres, or even without such guidance; the required condition being, that the influence of the Cerebrum shall be entirely withdrawn. Thus, numerous instances are on record, in which soldiers have continued to *march* in a sound sleep; and the Author has been assured by an intelligent witness, that he has seen a very accomplished pianist complete the performance of a piece of music in the same state.† A case has been mentioned to him by his friend Dr. William Budd, of a patient labouring under that form of epilepsy in which there was simply a temporary suspension of consciousness without convulsion, who, whenever the paroxysm came-on, persisted in the kind of movement in which he was engaged at the moment; and thus on one occasion fell into the water through continuing to walk onwards, and frequently (being a shoemaker by trade) wounded his fingers with the awl in his hand, by a repetition of the movement by which he was endeavouring to pierce the leather. Such facts as these add great strength to the probability, that when the Cerebral power is not suspended, but merely directed into another channel, as in the states of Reverie or Abstraction, and the attention is entirely drawn-off from the movements of locomotion, the continuance of these is due to the independent automatic action of the Spinal Cord, the *direction* being given to them by the Sensory Ganglia. This point, however, will be more fully considered hereafter (§ 523); at present it may be remarked, that, when a regular train of movements is being performed under such conditions, every single action may be probably regarded as affording the stimulus to the next; each contact of the foot with the ground, in the act of walking, exciting the muscular contractions which constitute the next step;‡ and each movement of the musician prompting that which has customarily followed it, after the same fashion.

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* See "Princ. of Comp. Phys.," §§ 649–654.

† In playing by memory on a musical instrument, the *muscular* sense often suggests the sequence of movements with more certainty than the *auditory;* and since the impressions derived from the muscles may prompt and regulate successional movements, without affecting the consciousness, there is no such improbability in the above statement as might at first sight appear.

‡ The truth of this view seems to the Author to be strongly supported by observation of the mode in which Infants learn to walk; for it may often be observed that long before they can stand, they will instinctively perform the movements of walking, if they be so supported that the feet touch the ground.

499. Now in all these cases, it seems reasonable to infer, that the same kind of connection between the excitor and motor nerves comes to be formed by a process of gradual development, as originally exists in the nervous systems of those animals whose movements are entirely automatic; this portion of the nervous system of Man being so constituted, as to *grow-to* the mode in which it is habitually called into play. Such an idea is supported by all that we know of the formation and persistence of *habits* of nervo-muscular action. For it is a matter of universal experience that such habits are far more readily acquired during the periods of infancy, childhood, and youth, than they are after the attainment of adult age; and that, the earlier they are acquired, the more tenaciously are they retained. Now it is whilst the organism is growing most rapidly, and the greatest amount of new tissue is consequently being formed, that we should expect such new connections to be most readily established; and, it is then, too, that the assimilative processes most readily take-on that new mode of action (§ 318), which often becomes so completely a 'second nature,' as to keep-up a certain acquired mode of nutrition through the whole subsequent life. It is an additional and most important confirmation of this view, to find that when a nerve-trunk has been cut-across, the re-establishment of its conductive power which takes-place after a certain interval is effected, not by the re-union of the divided fibres, but by the *development* of a new set of peripheral fibres in the place of the old ones (which undergo a gradual degeneration), this development proceeding from the point of section, and the central fibres remaining unaltered.*—That an actual continuity of nerve-fibres, however, is not requisite for the establishment of those connections between excitor and motor nerves, in which the central organs take part, seems probable from the fact, that under particular circumstances we find the influence of such impressions radiating in every direction, and extending to nerves which they do not ordinarily affect. Still there can be no doubt that the nerve-force is disposed to pass in special *tracks;* and it seems probable that whilst some of these are originally marked-out for the automatic movements, others may be gradually worn-in (so to speak) by the habitual action of the Will; and that thus, when a train of sequential actions primarily directed by the Will has been once set in operation, it may continue without any further influence from that source.

500. Another manifestation of the independent power of the Spinal Cord, is seen in its influence on *Muscular Tension.*—The various muscles of the body, even when there is the most complete absence of effort, maintain in the healthy state of the system a certain degree of firmness, by their antagonism with each other; and if any set of muscles be completely paralyzed, the opposing muscles will draw the part on which they act, out of its position of repose; as is well seen in the distortion of the face which is characteristic of paralysis of the facial nerve on one side. This condition has been designated as the *tone* of the Muscles; but this term renders it liable to be confounded with their *tonic contraction*, which is also concerned in maintaining their firmness, but which is a manifestation of the simple contractility of their tissue, and is exhibited alike by the striated and the non-striated forms of muscular fibre, but more

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* See Dr. Waller's important researches on the Reproduction of Nervous Substance, in "Müller's Archiv," 1852, heft iv.

especially by the latter. On the other hand, the condition now alluded-to, which may perhaps be appropriately termed their *tension*, is the result of a moderate though continued excitement of that contractility, through the nervous centres. It has been proved by Dr. M. Hall, that the Muscular Tension is dependent, not upon the influence of the Brain, but upon that of the Spinal Cord; as the following experiments demonstrate.—"Two Rabbits were taken; from one the head was removed; from the other also the head was removed, and the spinal marrow was cautiously destroyed with a sharp instrument: the limbs of the former retained a certain degree of firmness and elasticity; those of the second were perfectly lax." Again: "The limbs and tail of a decapitated Turtle possessed a certain degree of firmness or tone, recoiled on being drawn from their position, and moved with energy on the application of a stimulus. On withdrawing the spinal marrow gently out of its canal, all these phenomena ceased. The limbs were no longer obedient to stimuli, and became perfectly flaccid, having lost all their resilience. The sphincter lost its circular form and contracted state, becoming lax, flaccid, and shapeless. The tail was flaccid, and unmoved on the application of stimuli."* It is further remarked by Messrs. Todd and Bowman, that "a decapitated frog will continue in the sitting posture through the influence of the spinal cord; but immediately this organ is removed, the limbs fall apart."—This operation of the Spinal Cord is doubtless but a peculiar manifestation of its ordinary reflex function. A curious experiment by M. Brown-Séquard† shows that this effect is not due to loss of contractility in the muscles; for although, after division of the Spinal Cord, there is a temporary diminution in their power, after a short interval the muscles when stimulated to contract will not only raise an equal but even a greater weight than before, the effect lasting in healthy frogs for 24 hours or more. Thus, two Frogs, A and B, had weights fastened to the hind-legs until they were unable to raise them; the weighting amounted in each case to 925 grains. Immediately after division of the Cord they were able to

	5 min. after.	15 min. after.	25 min. after.	1 hour after.	2 hours after.	4 hours after.	24 hours after.	48 hours after.
A, 308 grains	694	925	1233	2003	2160	2160	2314	2314
B, 154 grains	463	617	925	1540	1851	2003	2160	2160

We shall hereafter see how much the influence of the Will in producing the active contraction of a muscle, is dependent upon sensations received from it; and it seems highly probable that the impression of the state of the muscle, conveyed by the afferent fibres proceeding from it to the spinal cord, is sufficient to excite this state of moderate tension through the motor nerves arising from the latter. Such a view derives probability from the fact, which must have fallen under the observation of almost every one, that most reflex actions become increased in energy, if resistance be made to them. Of this we have familiar examples in the action of the expulsor muscles which operate in defecation, urination, and parturition, if, when they are strongly excited, their efforts be opposed by spasmodic contraction of the sphincters, or by mechanical means. Many forms of convulsive movement exhibit the same tendency, their violence being proportional to the mechanical force used to restrain them. Here it is evident that the *impression of resistance* conveyed to the Spinal Cord, is the source of the increased energy of its motor influence; from which we may fairly infer that the moderate resistance occasioned by the natural antagonism of the muscles, is the source of their continued and moderate tension, whilst they are under the influence of the Spinal Cord. This constant though gentle action serves to keep-up the nutrition of the muscles which are paralyzed to the will; and this is still more completely maintained, if the portion of the nervous centres with which they remain connected be so unduly irritable, that the muscles are called into contraction upon the slightest excitation, and are thus continually exhibiting twitchings, startings, or more powerful convulsive movements. It is upon the continuance of the nutrition of the muscles, that the persistence of their contractility depends; and hence the Spinal Cord has an indirect influence upon this peculiar property, which is more likely to be retained when the muscle is still subject to the influence of the Spinal Cord, though cut-off from that of the Brain, than when it is completely paralyzed by the entire severance of its connection with the nervous centres.

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* "Memoirs on the Nervous System," 1837, p. 93. † "Comptes Rendus," 1847.

3. *Of the Sensory Ganglia and their Functions.—Consensual Movements.*

501. At the base of the Brain in Man, concealed by the Cerebral Hemispheres, but still readily distinguishable from them, we find the series of ganglionic masses which have been already mentioned as being in direct connection with the nerves of Sensation, and which appear to have functions quite independent of those of the other components of the Encephalon. These are the Olfactory and Optic ganglia (Corpora Quadrigemina), with the Auditory and Gustatory centres contained in the Medulla Oblongata. The structure of the Corpora Quadrigemina has been shown by Mr. Lockhart Clarke* to consist of nerve-cells together with oblique, transverse, and longitudinal nerve-fibres resting on an arched transparent lamina, which forms the roof of the Sylvian Aqueduct. A large proportion of the Optic tract is connected with the nates.—But besides these, at the base of the Cerebral Hemispheres, we find two other large ganglionic masses on either side, through which nearly all the fibres appear to pass that connect the Hemispheres with the Medulla Oblongata: namely, the *Thalami Optici*, and the *Corpora Striata.* Now, although these are commonly regarded in the light of appendages merely to the Cerebral Hemispheres, it is evident from the large quantity of vesicular matter they contain, that they must rank as independent ganglionic centres; and this view is supported alike by the evidence of Comparative Anatomy, and by that afforded by the history of Development. For it is certain that the size of the Thalami Optici and Corpora Striata presents no more relation, in different tribes of animals, to that of the Cerebrum, than does that of the ganglia of Special Sense; and they may even present a considerable development, when the condition of the Cerebrum is quite rudimentary. Thus in the Osseous Fishes, a careful examination of the relations of the body which is known as the Optic lobe (Fig. 91, c) makes it apparent that this is the representative, not merely of the proper Optic ganglion of Man, but also of the Thalamus Opticus; whilst, again, the mass which is designated as the Cerebral lobe

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* "Proceedings of the Royal Society," June 20, 1861.

(B) is chiefly homologous with the Corpus Striatum of higher animals. The nature of the latter body is made apparent, in the higher Cartilaginous Fishes, by the presence of a ventricle in its interior; the floor of this cavity being formed by the Corpus Striatum, whilst the thin layer of nervous matter which forms its roof is the only representative of the Cerebral hemisphere. So in the Human embryo of the 6th week, we find a distinct vesicle for the Thalami Optici, interposed between the vesicle of the Corpora Quadrigemina and that which gives origin to the Cerebral Hemispheres; whilst the Corpora Striata constitute the floor of the cavity or ventricle which exists in the latter, this being as yet of comparatively small dimensions.—Now, as already pointed-out (§ 475), we may distinguish in the Medulla Oblongata and Crura Cerebri a *sensory* and a *motor* tract, by the endowments of the nerves which issue from them. The sensory tract may be traced upwards, until it almost entirely spreads itself through the substance of the Thalamus. Moreover, the Optic nerves and the peduncles of the Olfactive may be shown to have a distinct connection with the Thalami, the former by the direct passage of a portion of their roots into these ganglia, and the latter through the medium of the Fornix. Hence we may fairly regard the *Thalami Optici* as the chief focus of the *Sensory* nerves, and more especially as the ganglionic centre of the nerves of *common* sensation, which ascend to it from the Medulla Oblongata and Spinal Cord.—On the other hand, the *Corpora Striata* are implanted on the *Motor* tract of the Crura Cerebri, which descend into the Pyramidal columns; and their relation to the fibres of which that tract is composed, appears to be essentially the same as that which the Thalami bear to the sensory tract.—The Corpora Striata are connected with each other, on the median plane, by the *anterior* commissure; and the Thalami Optici, by the *soft* and the *posterior* commissures. The Corpus Striatum and Thalamus Opticus of the same side are very closely connected by commissural fibres, stretching from one to the other; and, if the preceding account of the respective offices of these bodies be correct, they may be regarded as having much the same relation to each other, as that which exists between the posterior and anterior peaks of vesicular matter in the Spinal Cord;* the latter issuing motor impulses in respondence to sensations excited through the former. They are also intimately connected with other ganglionic masses in their neighbourhood, such as the 'locus niger,' and the vesicular matter of the 'tuber annulare;' which, again, are in close relation with the vesicular matter of the Medulla Oblongata.

502. It has been commonly supposed that the fibres of the Crura Cerebri, after entering the Corpora Striata and Thalami Optici, pass continuously through these bodies, receiving 'reinforcements' of additional fibres from their ganglionic matter; and that they then radiate to the internal surface of the grey matter of the Cerebral Hemispheres. Such would certainly be the conclusion to which a superficial examination of their course would lead. But very strong reasons have recently been advanced for the belief, that the fibres of the Crura Cerebri for the most part, if not entirely, terminate in the vesicular substance of the Corpora Striata and Thalami Optici; and that the radiating fibres of the Hemispheres take a fresh departure from these ganglia, serving, in fact, the part of commis-

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* This was first pointed-out by Messrs. Todd and Bowman, in their "Physiological Anatomy," vol. i. pp. 347-350.

sures to connect *their* vesicular substance with that of the Cerebral ganglia.* And this view, as we shall hereafter see, is in complete accordance with the existence of a very decided *physiological* separation between these two sets of organs.—Altogether it is very evident, that a series of true ganglionic centres exists at the base of the Encephalon, which are really as distinct from either the Cerebrum or Cerebellum as the latter are from each other; and as these centres are in immediate connection with the nerves both of *special* and of *general* Sense, they may be appropriately designated the *Sensory Ganglia.*—An inquiry into the distribution and endowments of their nerves will assist us in the determination of the functions of the central organs in which they terminate.

503. *Nerves of Special Sense.*—Through the First pair, or *Olfactory* nerve, are transmitted the impressions made by odorous emanations upon the surface it supplies; and it is not susceptible to impressions of any other kind. Anatomical examination of the distribution of this nerve proves that it is not one which directly conveys motor influence to any muscles, since all its branches are distributed to the membrane lining the nasal cavity; and experimental inquiry leads to the same result, for no irritation of the peduncles or branches excites any muscular movement. Further, no irritation of any part of this nerve excites reflex actions through other nerves. Again, it is not a nerve of 'common' sensation; for animals exhibit no signs of pain when it is subjected to any kind of irritation. Neither the division of the nerve, nor the destruction of the olfactive ganglia, seems to inconvenience them materially. They take their food, move with their accustomed agility, and exhibit the usual appetites of their kind. The 'common' sensibility of the parts contained in the olfactive organ is in no degree impaired, as is shown by the effect of irritating vapours; but the animals are destitute of the sense of smell, as is shown by the way in which these vapours affect them; for at first they appear indifferent to their presence, and then suddenly and vehemently avoid them as soon as the Schneiderian membrane becomes irritated. Moreover, if two dogs, with the eyes bandaged, one having the olfactory nerves and ganglia sound, and the other having had them destroyed, are brought into the neighbourhood of the dead body of an animal, the former will examine it by its smell; whilst the latter, even if he touches it, pays no attention to it. This experiment Valentin† states that he has repeated several times, and always with the same results. Further, common observation shows that *sensibility to irritants*, such as snuff, and *acuteness of smell*, bear no constant proportion to one another; and there is ample pathological evidence, that the want of this sense is connected with some morbid condition of the olfactory nerves or ganglia.—It is well known that Magendie has maintained, that the Fifth pair in some way furnishes conditions requisite for the exercise of the power of smell; asserting that, when it is cut, the animal is deprived of this sense. But his experiments were made with irritating vapours, which excite sternutation or other violent muscular actions, not through the Olfactory nerve, but through the Fifth pair; and the experiments of Valentin, just related, fully prove that the animals are not sensitive to *odours*, strictly so called, after the Olfactory nerve has been divided. The acuteness of the true sense of smell is

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* See especially Messrs. Todd and Bowman's "Physiological Anatomy," vol. i. p. 277; and Prof. Kölliker's "Mikroskopische Anatomie," band ii. § 118.

† "De Functionibus Nervorum Cerebralium," &c., Bernæ, 1839.

lessened by section of the Fifth pair; but this is because the Schneiderian membrane is then no longer duly moistened by its proper secretion, and when dry it is less susceptible of the impressions made by those minute particles of odoriferous substances, to which the excitement of the sensation must be referred.

504. That the Second pair, or *Optic* nerve, has an analogous character, appears alike from anatomical and experimental evidence. No chemical or mechanical stimulus of the trunk produces *direct* muscular motion; nor does it give rise, so far as can be ascertained, to indications of pain; whence it may be concluded that this nerve is not one of 'common' sensation. That the ordinary sensibility of the eyeball remains, when the functions of the Optic nerve are completely destroyed, is well known; as is also the fact, that division of it puts an end to the power of vision. Valentin states that, although the Optic nerve may, like other nerves, be in appearance completely regenerated, he has never been able to obtain any evidence that the power of sight has been in the least degree recovered. He remarks that animals suddenly made blind exhibit great mental disturbance, and perform many unaccustomed movements; and that the complete absence of the power of vision is easily ascertained. Morbid changes are sometimes observed to take place in eyes whose Optic nerve has been divided; but these are by no means so constant or so extensive, as when the Fifth pair is paralyzed; and they may not improbably be attributed to the injury occasioned by the operation itself, to the parts within the orbit.

505. The Optic nerve, though analogous to the Olfactory in all the points hitherto mentioned, differs from it in one important respect;—that it has the power of conveying impressions which excite *reflex* muscular motions. This is especially the case in regard to the Iris, the ordinary actions of which are regulated by the degree of light impinging on the retina. When the Optic nerve is divided, contraction of the pupil takes place; but this does not occur, if the connection of this nerve with the third pair, through the nervous centres, be in any way interrupted. After such division (if complete), the state of the pupil is not affected by variations in the degree of light impinging on the retina; except in particular cases, in which it is influenced through other channels. Thus, in a patient suffering under amaurosis of one eye, the pupil of the affected eye is often found to vary in size, in accordance with that of the other eye; but this effect is due to the action of light on the retina of the sound eye, which produces a motor change in the Third pair on both sides. Further, as already shown (§ 496), the *impression* only of light upon the retina may give rise to contraction of the pupil, by reflex action, when the Optic nerve is itself sound; whilst no *sensations* are received through the eye, in consequence of disease in the sensorial portion of the nervous centres. Although the contraction of the pupil is effected by the influence of motor fibres, which proceed to the sphincter of the Iris from the third pair of nerves, *through* the Ophthalmic ganglion, its dilatation (as we shall hereafter see) depends upon the influence it derives from the Sympathetic system, of which that ganglion forms part.—Besides the contraction of the pupil, another action of a 'reflex' character is produced through the Optic nerve; namely, the contraction of the Orbicularis muscle under the influence of strong light, or when a foreign body is suddenly brought near the eye. But this cannot be excited without a consciousness of the visual impression; in fact, it is a movement of a 'consensual' kind, pro-

duced by the painful sensation of light, which gives rise to the condition well characterized by the term *photophobia.* The involuntary character of it must be evident to every one who has been engaged in the treatment of diseases of the eyes; and the effect of it is aided by a similarly-involuntary movement of the eyeball itself, which is rotated upwards and inwards, to a greater extent than the Will appears able to effect.—Another reflex movement excited through the visual sense, is that of Sneezing, which is induced in many individuals by the sudden exposure of the eyes to a strong light: of the purely automatic character of this movement there can be no question, since it cannot be imitated voluntarily; and that it is not excito-motor, is proved by the fact that it is not excited unless the light be *seen.*[*]

506. There is a further peculiarity, of a very marked kind, attending the course of the Optic nerves; this is the crossing or 'decussation' which they undergo more or less completely, whilst passing between their ganglia and the eyes. In some of the lower animals, in which the two eyes (from their lateral position) have entirely different spheres of vision, the decussation is complete; the whole of the fibres from the right optic ganglion passing into the left eye, and *vice versâ.* This is the case, for example, with most of the Osseous Fishes (as the cod, halibut, &c.); and also, in great part at least, with Birds.[†] In the Human subject, however, and in animals which, like him, have the axes of both eyes directed to the same object, the decussation seems less complete; but there is a very remarkable arrangement of the fibres, which seems destined to bring the two eyes into peculiarly consentaneous action. The *posterior* border of the Optic Chiasma is formed exclusively of *commissural* fibres, which pass from one *optic ganglion* to the other, without entering the real optic nerve. Again, the *anterior* border of the Chiasma is composed of fibres, which seem, in like manner, to act as a commissure between the two *retinæ;* passing from one to the other, without any connection with the optic ganglia. The tract which lies between the two borders, and occupies the *middle* of the Chiasma, is the true Optic Nerve; and in this it would appear that a portion of the fibres decussates, whilst another portion passes directly from each Optic ganglion into the corresponding eye. The fibres which proceed from the ganglia to the retinæ, and constitute the proper Optic Nerves, may be distinguished into an internal and an external tract. Of these the *external,* on each side, passes directly onwards to the eye of *that* side: whilst the *internal* crosses over to the eye of the *opposite* side. The distribution of these two sets of fibres in the retina of each eye respectively, is such that, according to Mr. Mayo, the fibres from either optic ganglion will be distributed to *its own side* of *both* eyes;[‡] the right optic ganglion

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[*] A patient was for some time in the London Hospital, in whom there was such an undue impressibility of the retina, that she could not remain in even a moderate light without a continual repetition of the act of Sneezing.

[†] See Solly on "The Human Brain," 2nd edit., p. 288.

[‡] This arrangement was first hypothetically suggested by Dr. Wollaston ("Philos. Trans.," 1824), as facilitating the explanation of some of the phenomena of vision, and more particularly single vision with two eyes. We shall hereafter see, however, that the singleness of the impression resulting from the formation of two pictures upon our retinæ, is not attributable to any such anatomical arrangement, their combination being a mental process, and the fusion of two *dissimilar* pictures being requisite to enable us to exercise one of the highest attributes of the visual sense, the perception of *projection.* (See CHAP. XV.

being thus exclusively connected with the outer part of the retina of the right eye, and with the inner part of the retina of the left; whilst the left optic ganglion is connected exclusively with the outer side of the left retina, and with the inner side of the right. Now as either side of the eye receives the images of objects which are on the other side of its axis, it follows, if this account of the distribution of the nerves be correct, that in Man, as in the lower animals, each ganglion receives the impressions of objects situated on the *opposite* side of the body. The purpose of this decussation may be, to bring the visual impressions, which are so important in directing the movements of the body, into proper harmony with the motor apparatus; so that the decussation of the motor fibres in the pyramids being accompanied by a decussation of the optic nerves, the same effect is produced as if neither decussated,—which last is the case with Invertebrated animals in general.* The view above stated has received important corroboration from the interesting observation of Mr. Towne, that a blending of two colours occurs if their images are simultaneously presented to the *inner* side of one retina and the *outer* side of the other retina, but not otherwise.

507. The functions of the *Auditory* nerve, or *Portio Mollis* of the 7th, are easily determined, by anatomical examination of its distribution, and by observation of pathological phenomena, to be analogous to those of the two preceding. Atrophy or lesion of the trunk destroys the sense of Hearing; whilst irritation of it produces auditory sensations, but does not occasion pain. From experiments made upon the nerve before it leaves the cranial cavity, it appears satisfactorily ascertained that this nerve is not endowed either with common sensibility or with the power of directly stimulating muscular movement. Nor can any obvious reflex actions be executed by irritation of this nerve; but it seems nevertheless by no means improbable, that the muscles which regulate the tension of the Tympanum are called into action by impressions made upon it and reflected through the auditory ganglion, in the same manner as the diameter of the pupil is regulated through the optic nerve. In the involuntary start, however, which is occasioned by a loud and sudden sound, we have an example of a *consensual* movement excited through the Auditory nerve, which is evidently analogous to the closure of the eyes to a strong light. In certain morbidly-impressible states of the nervous system, as will be presently shown (§ 521), the effect of sounds on the motor apparatus is far more remarkable.—It has been attempted by Flourens to show, that the division of the Auditory nerve, which proceeds to the Semicircular canals, has functions altogether different from that portion which supplies the Vestibule and Cochlea. This inference, however, is grounded only upon the movements exhibited by animals in which these nerves are irritated; which movements are capable of a different explanation (§ 514).

508. The nerves which minister to the sense of *Taste* are destitute of the peculiarities which distinguish the preceding; being no other than certain branches of ordinary afferent nerves,—the Fifth Pair and Glosso-

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* For additional facts bearing on this subject, see the observations of Mr. Towne 'On the Stereoscope and Stereoscopic Results,' in "Guy's Hospital Reports" for 1862, p. 69, and 1863, p. 103.

pharyngeal (§ 480)—the peculiar endowments of which seem to depend rather upon the structure and actions of the papillæ at their peripheral extremities, than upon anything special in their own character; for, as in the case of the ordinary nerves of 'common' sensation, mechanical irritation applied to them calls-forth indications of pain.—From the observations and experiments of M. Cl. Bernard,* it appears that the Facial nerve (portio dura of the 7th) supplies some condition requisite for the sense of Taste, through the branch known as the Chorda Tympani, which is the motor nerve of the Lingualis muscle and Submaxillary gland (§ 80). When paralysis of the Facial exists in Man, the sense of taste is very much impaired on the corresponding side of the tongue, provided that the cause of the paralysis be seated above the origin of the Chorda Tympani from its trunk. Similar results have been obtained from experiments upon other animals. The effect may possibly be attributable to the secretion of Saliva being interfered with.

509. *Nerves of Common Sensation.*—To the sense of *Touch* all the afferent nerves of the body (save the nerves of special sense) appear to minister; in virtue—according to the doctrine already propounded (§ 472)—of the direct connection of certain of their fibrils with the *Sensorium commune.* But the degree in which they are capable of producing Sensations does not bear any constant relation to their power of exciting reflex actions. Thus, the Glosso-pharyngeal is not nearly so *sensitive* as the Fifth pair; though more powerful as an *excitor* nerve. The Par Vagum appears to have even less power of arousing sensory changes; although it is the most important of all the excitors to reflex action. So again, the afferent nerves of the inferior extremities, in Man, are less concerned in ministering to sensations, than are those of the superior; and yet they appear to be much more efficient as excitors to muscular movement.—These differences may be accounted-for, by supposing that the proportion which the fibres having their centre in the ganglionic matter of the Spinal Cord, bears to that of the fibres which pass-on to the Sensorium, is not constant, but is liable to variation in different nerves; the former predominating in the Par Vagum and the Glosso-pharyngeal, whilst the latter are more numerous in the Fifth Pair, and in most of the Spinal nerves.

510. *Motor Nerves.*—No motor nerves issue from the Sensory Ganglia with the same directness that afferent nerves proceed towards them; but the reflex actions of these centres find a ready channel in the motor nerves of the Cranio-Spinal axis generally. For, as we have seen (§ 501), the motor tract of the Crura Cerebri, which is in connection with the motor Encephalic nerves, and also (through the vesicular substance of the Spinal Cord) with the anterior roots of the Spinal nerves, passes-up into the Corpora Striata and Corpora Quadrigemina. Although the direct connection of the other ganglia of Special Sense with the Motor columns is at present a matter of presumption only, yet this presumption is strongly supported by the analogy of the Optic ganglia; the distinctness of this connection in *their* case being easily accounted-for, when it is remembered in how great a degree the general movements of the body are guided by the visual sense.

511. *Functions of the Sensory Ganglia.*—We have now to consider

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* "Archives Générales de Médecine," 1844.

what deductions may be drawn with regard to the functions of the Sensory Ganglia in Man, from the facts supplied by Comparative Anatomy, by Experimental inquiry, and by Pathological phenomena. The determination of these functions may seem to be the more difficult, as it is impossible to make any satisfactory experiments upon the ganglionic centres in question, by isolating them completely from the Cerebral Hemispheres above, and from the Medulla Oblongata and Spinal Cord below. But the evidence derived from Comparative Anatomy appears to be in this case particularly clear; and, rightly considered, affords us nearly all the information we require. In the series of "experiments prepared for us by nature," which is presented to us in the descending scale of Animal life, we witness the effects of the gradual change in the relative development of the Sensory ganglia and Cerebral hemispheres, which are presented to us in descending through the Vertebrated scale; and the results of the entire withdrawal of the latter, and of the sole operation of the former, which are exhibited in the higher Invertebrata (see §§ 429, 432).* —Thus we are led by the very cogent evidence which Comparative Anatomy supplies, to regard this series of Ganglionic centres as constituting the real *Sensorium;* each ganglion having the power of rendering the Mind conscious of the impressions derived from the organ with which it is connected. If this position be denied, we must either refuse the attribute of consciousness to such animals as possess no other Encephalic centres than these; or we must believe that the *addition* of the Cerebral hemispheres, in the Vertebrated series, *alters* the endowments of the Sensory ganglia,—an idea which is contrary to all analogy.

512. So far as the results of Experiments can be relied-on, they afford a corroboration of this view. The degree in which animals high in the scale of organization can perform the functions of life, without any other centre of action than the Ganglia of Special sense, the Medulla Oblongata, and the Cerebellum, appears extraordinary to those who are accustomed to regard the Cerebral Hemispheres as the centre of all energy. From the experiments of Flourens,† Hertwig,‡ Magendie,§ Longet,‖ and others, it appears that not only Reptiles, but Birds and Mammals, may survive for many weeks or even months (if their physical wants be duly supplied) after the removal of the entire Cerebrum. It is difficult to substantiate the existence in them of actual *sensation;* but some of their movements appear to be of a higher kind than those resulting from mere excito-motor action. One of the most remarkable phenomena exhibited by such a being, is the power of maintaining its equilibrium, which could scarcely

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[*] It is worthy of special notice, that the development of the Cephalic ganglia in the Invertebrata always bears an exact proportion to the development of the *eyes;* the other organs of special sense being comparatively undeveloped; whilst these, in all the higher classes at least, are instruments of great perfection, and are evidently connected most intimately with the direction of the movements of the animals. Of this fact we have a remarkable illustration in the history of the metamorphosis of Insects; the eyes being almost rudimentary, and the Cephalic ganglia comparatively small, in most Larvæ; whilst both these organs attain a high development in the Imago, to whose actions the faculty of sight is essential.

[†] "Recherches Expérimentales sur les Propriétés et les Fonctions du Système Nerveux," 2nd edit., 1845.

[‡] "Exper. de effect. læsion. in partibus Encephali," Berol., 1826.

[§] "Leçons sur les Fonctions du Système Nerveux," Paris, 1839.

[‖] "Traité de Physiologie," tom. ii. partie 2, 1860, p. 411.

exist without consciousness. If it be laid upon the back, it rises again; if pushed, it walks. If a Bird thus mutilated be thrown into the air, it flies; if a Frog be touched, it leaps. It swallows food and liquid, when they are placed in its mouth; and the digestive operations, the acts of excretion, &c., take place as usual. In the case of a Pigeon experimented-on by Malacorps, which is recorded by Magendie, there appears sufficient proof of the persistence of a certain amount of sensation. Although the animal was not affected by a strong light suddenly made to fall upon its eyes, it was accustomed, when confined in a darkened or partially-illuminated room, to seek-out the light parts; and *it avoided objects that lay in its way.* In the same manner, it did not seem to be affected by sudden noises; but at night, when it slept with its eyes closed and its head under its wing, it would raise its head in a remarkable manner, and open its eyes, on the slightest noise; speedily relapsing into a state of complete unconsciousness.' Its principal occupation was to prune its feathers and scratch itself. And Longet mentions that a Pigeon from which he had removed the entire Cerebrum, gave many indications of consciousness of light; for not only did the pupil contract, but the lids closed, when a strong light was suddenly made to fall upon the eye, the animal having been previously kept in darkness; and *when a lighted candle was made to move in a circle before it, the animal executed a corresponding movement with its head.**—The condition of such beings seems to resemble that of a Man, who is in a slumber sufficiently deep to lose all distinct *perception* of external objects, but who is yet conscious of *sensations*, as appears from the movements occasioned by light or by sounds, or from those which he executes to withdraw the body from an uneasy position.

513. The results of other experiments made upon the Sensory ganglia themselves, and upon the organs from which they derive their impressions, confirm this view; by showing that the ordinary movements are seriously perturbed, and that in some instances a new set of automatic movements is induced, when the normal relations between the sensory and motor apparatus are disarranged. Of the functions of the ganglia of special sense, those of the *Corpora Quadrigemina* are the chief which have been examined experimentally. The researches of Flourens and Hertwig have shown, that the connection of these bodies with the visual function, which might be inferred from their anatomical relations, is thus substantiated. The partial loss of the ganglion on one side produces partial loss of power and temporary blindness on the opposite side of the body, without necessarily destroying the mobility of the pupil; but the removal of a larger portion, or complete extirpation of it, occasions permanent blindness and immobility of the pupil, with temporary muscular weakness on the opposite side. This temporary disorder of the muscular system sometimes manifests itself in a tendency to move on the axis, as if the animal were giddy. No disturbance of consciousness appears to be produced; and Hertwig states that he never witnessed the convulsions, which Flourens mentions as a consequence of the operation, and which were

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* It must not be forgotten that, in such experiments, the severity of the operation will of itself occasion a suspension or disturbance of the functions of parts that remain; so that the *loss* of a power must not be at once inferred from the absence of its manifestations. But the *persistence* of a power, after the removal of a particular organ, is a clear proof that it cannot be the peculiar attribute of that organ.

probably occasioned by his incision having been carried too deeply. As Longet has justly remarked, it is difficult, if not impossible, to remove one or both of these ganglionic masses, without doing such an injury to the Crura Cerebri on which they repose, as shall in great degree account for such disturbed movements (§ 517). Irritation of *one* of the Tubercula Quadrigemina has been observed, both by Flourens and Longet, to produce contraction of the pupils of *both* eyes.—These results of experiment are partly confirmed by Pathological phenomena in Man; for there are many instances on record, in which blindness has been one of the consequences of diseased alterations in one or both tubercles; and in some of the cases in which the lesion extended to parts seated beneath the tubercles, disturbed movements were observed.—The subservience of these bodies to the exercise of the visual sense, appears, on the whole, to be the point best established in regard to their functions; and considering the degree in which this sense is concerned in the regulation of the general movements of the body, it is not surprising that lesions of its centre should occasion a perversion of these movements. This appears the more probable from the fact, that, in animals whose Sensory ganglia bear so large a proportion to the whole Encephalon, that we must look upon them as the principal centres of motor activity, instead of being chiefly concerned (as in Man) in the mere guidance of movements whose origin is Cerebral, lesions of the organ of sense from which the impressions that excite the sensori-motor impulses are derived, produce a corresponding disturbance. Thus Flourens found that a vertiginous movement may be induced in Pigeons by simply blinding one eye; and Longet produced the same effect by evacuating the humours of the eye.

514. It is probably on the same principle, that we are to account for the remarkable results obtained by Flourens* from section of the portion of the Auditory nerve proceeding to the Semicircular canals. Section of the horizontal semicircular canal in Pigeons, on both sides, induces a rapid jerking horizontal movement of the head, from side to side; and a tendency to turn to one side, which manifests itself whenever the animal attempts to walk forwards. Section of a vertical canal, whether the superior or inferior, of both sides, is followed by a violent vertical movement of the head. And section of the horizontal and vertical canals, at the same time, causes horizontal and vertical movements. Section of either canal on one side only, is followed by the same effect as when the canal is divided on both sides; but this is inferior in intensity. The movements continue to be performed during several months. In Rabbits, section of the horizontal canal is followed by the same movements as are exhibited by Pigeons; and they are even more constant, though less violent. Section of the anterior vertical canal causes the animal to make continued forward 'somersets;' whilst section of the posterior vertical canal occasions continued backward 'somersets.' The movements cease when the animal is in repose; and they recommence when it begins to move, increasing in violence as its motion is more rapid.—These curious results are supposed by M. Flourens to indicate, that the nerve supplying the semicircular canals does not minister to the sense of hearing, but to the direction of the movements of the animal; but they are fully explained upon the supposition, that the normal function of the semicircular canals

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* Op. cit.

is to indicate to the animal the *direction* of sounds, and that its movements are partly determined by these; so that a destruction of one or other of them will produce an irregularity of movement (resulting, as it would seem, from a sort of giddiness on the part of the animal), just as when one of the eyes of a bird is covered or destroyed, as in the experiments previously cited.

515. The numerous experiments which have been made for the purpose of determining the functions of the Thalami Optici and Corpora Striata, have not yielded any very satisfactory results; and this on account of the impossibility of completely isolating them, in such a manner as to limit the operation (whether this be section, removal, or irritation) to them alone. Thus it is impossible to remove them, either separately or conjointly, without first removing the Cerebral Hemispheres; and the Thalami cannot be entirely removed, without dividing the stratum of fibres which traverse their deeper portion in their passage to the Corpora Striata. —The Thalami Optici have not that relation to the visual sense which their designation would imply; for (according to the affirmation of Longet) they may be completely destroyed in Mammals and Birds, without destruction of sight or loss of the activity of the pupil. And irritation of one or both of them produces no contraction of the pupil. It seems probable, therefore, that the loss of sight with dilatation and immobility of the pupil, which is frequently observed in cases of apoplectic effusion into the substance of the Thalami, is really due to the compression of the Optic nerves which lie beneath them. These bodies appear, however, to possess a very decided influence on the power of voluntary movement; for although an animal maintains its balance, and can be made to move onwards, after the removal of the Cerebral Hemispheres, and even after the removal of the Corpora Striata, yet if either of the Thalami Optici be removed, the sensibility and power of voluntary movement are destroyed on the *opposite* side of the body, and the animal consequently falls over to that side (Longet). If, instead of the entire removal of one of the Thalami, an incision be made in it without the previous removal of the Cerebrum, the animal keeps turning to one side in a circular manner (*évolution du manège*): according to Longet and Lafargue, this movement is directed in the rabbit towards the opposite side; whilst Flourens states that in the frog its direction is towards the injured side; and according to Schiff* the destruction of the three anterior fourths of this organ in the rabbit determines this movement towards the injured side, whilst that of the posterior fourth determines the movement towards the opposite side. Brown-Séquard attributes the rolling movements in many of these cases to certain muscles being in a state of spasm, in other instances to vertigo. No mechanical irritation of the Thalami produces either signs of pain or muscular movement; and this fact might at first appear to negative the doctrine that these organs are the ganglia of common sensation. But it must be borne in mind that the production of pain by mechanical injuries is by no means an universal phenomenon in the case of the nerve-*trunks* which minister to sensation,—the olfactive, optic, and auditory nerves being exempted; and it need occasion still less surprise, therefore, that a nervous *centre* should be destitute of this kind of impressibility, which we have seen to be wanting also in the Spinal Cord.

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* Roser and Wunderlich's "Archiv für Physiol. Heilkunde," 1846, § 667.

516. The effects of lesions of the Corpora Striata are less distinctly marked. It was affirmed by Magendie that there exists in them a motor power which excites *backward* movement, and that a corresponding power of exciting *forward* movement exists in the Cerebellum; that these two powers ordinarily balance one another; but that if either organ be removed, the power of the other will occasion a continual automatic movement, the removal of the Corpora Striata causing an irresistible tendency to forward progression, whilst the division of the peduncles of the Cerebellum (according to him) occasions the reverse movement. These assertions, however, have not been confirmed by other experimenters. According to Longet,* Schiff,† and Lafargue,‡ the results of removal of the Corpora Striata with the anterior part of the Cerebral hemispheres, are for the most part negative; for the animal usually remains in a state of profound stupor, although still retaining the erect position; and it is only when irritated by pinching or pricking, that it will execute any rapid movements. No mechanical irritation of the Corpora Striata produces either signs of pain or muscular movement.

517. When the fibrous tracts which connect these ganglionic masses with the Medulla Oblongata, and which are commonly (but erroneously) designated as the *Crura Cerebri*, are completely divided, the result, as might be anticipated, is the annihilation of sensibility and of the power of voluntary movement in the body generally.§ When, however, the Crura Cerebri of a rabbit are not completely divided, but one of them is partially cut-through, a little in front of the Pons Varolii, the animal is said by Longet and Schiff to exhibit a constant tendency to turn towards the side opposite to that of the lesion, so that it performs the circular *évolution du manège;* the diameter of its circle of movement being smaller, in proportion as the incision approaches the edge of the Pons. But if one of the Crura be completely divided, the animal then falls-over on the opposite side; the limbs of that side being paralyzed to the influence of the Encephalic centres, though they may be still caused to exhibit reflex motions. Hence it appears that the circular movements which are performed after incomplete lesions of the Crus Cerebri and Thalamus Opticus of either side, are due to the weakening of the sensori-motor apparatus of the opposite side, whereby the balance of the muscular actions of the two sides is destroyed. Nearly the same results have been obtained on this point by Longet, Lafargue, and Schiff.

518. Considerable importance is attached by some Physiologists to the part of the Encephalon known as the *Tuber Annulare*, to which the name of *Mesocephale* has also been given. This is not altogether synonymous with the *Pons Varolii*, as some Anatomists have represented it; for, while the latter consists of transverse fibres which form the commissure

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[*] Op. cit. [†] "De vi motoriâ baseos Encephali," Bockenhemii, 1845.

[‡] "Essai sur la Valeur des Localisations Encéphaliques," &c., Thèse Inaug., Paris, 1838.

[§] It is considered by Longet that these functions are not *completely* destroyed, because the animals on whom this operation has been performed still retain some power of movement, and respond by cries to impressions that ordinarily produce pain. There is no proof, however, that such actions are other than 'excito-motor;' they certainly cannot in themselves be admitted as proving the persistence of consciousness in the lower segment of the Cerebro-Spinal axis. (See Brown-Séquard, "Central Nervous System," 1860, p. 225; and Schroeder v. d. Kolk, Syd. Soc. Trans., 1859, p. 76.)

between the hemispheres of the Cerebellum, surrounding and passing between the longitudinal fibres of the Sensory and Motor tracts which constitute the Crura Cerebri, the Tuber Annulare (which exists in animals whose Cerebellum has no hemispheres) is a projection from the surface of the proper Medulla Oblongata, containing a considerable nucleus of vesicular matter. M. Brown-Séquard* has drawn the following conclusions respecting the functions of this part of the Encephalon, chiefly based on pathological evidence:—1. That the restiform bodies and their prolongations into the Pons, and into the Cerebellum, are not, as has been supposed, the conductors of sensory impressions. 2. That whilst hyperæsthesia occurs on the same side of the body, when the Spinal Cord is injured, especially in its posterior part, it appears on the opposite side of the body when a section is made either of the anterior or posterior surface of the Pons; and this he believes to favour his view of the decussation of the sensory fibres in the Cord, and to be opposed to the old view of the decussation of these fibres below the Tubercula Quadrigemina, or in the substance of the Pons itself. 3. The transmission of sensory impressions in the Pons appears to be chiefly effected by its central portion, whilst the anterior portion is chiefly instrumental in the conduction of the mandates of the Will to the Muscles. The experiments of Longet led him to the conclusion, that the Tuber Annulare, the structure of which is very complicated, is an independent centre of sensation and of motor power; but they do not afford any clear information as to its special attributes. He states, however, that convulsive movements are excited by irritating it, and especially by the transmission of an electric current through its substance. These movements, however, according to the testimony of Dr. Todd, appear to be of a different character from those which are excited by the application of the same stimulus to the Spinal Cord and Medulla Oblongata; for he states that whilst the convulsions excited by the transmission of the current of the magneto-electric machine through the parts just named, are *tetanic*, the muscles being thrown into a state of *fixed* contraction,—those which ensue when the current is transmitted through the region of the Mesocephale and Corpora Quadrigemina, are *epileptic*, being combined movements of *alternate* contraction and relaxation, flexion and extension, affecting the muscles of all the limbs, of the trunk, and of the eyes, which roll-about just as in epilepsy.†

519. The evidence afforded by Pathology regarding the functions of these Ganglionic masses, is far from being self-consistent; and this arises, it may be surmised, from the circumstance that the effects of morbid changes (particularly of sanguineous effusions) in any part of the Encephalon, extend themselves to other parts than those in which the obvious lesions are found; as is abundantly proved by the great variety of phenomena which present themselves as the results of lesions apparently similar, and by the similarity of the phenomena that are frequently consequent upon lesions of very different parts. So far as is yet known, extensive disease of either the Thalamus Opticus or the Corpus Striatum, of one

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* "Journ. de la Physiol.," vol. i. p. 762; vol. ii. p. 121.

† Lumleian Lectures 'On the Pathology and Treatment of Convulsive Diseases,' in "Medical Gazette," May 11, 1849.

side produces hemiplegia, or paralysis both of sensation and motion, on the opposite side. The same result very commonly follows an apoplectic effusion into the substance of either; and although it has been maintained that when the lesion is limited to the Corpus Striatum the posterior member is peculiarly or alone affected, and that lesion of the Thalamus Opticus alone has a special tendency to occasion paralysis of the anterior member, yet the careful analysis which has been made by Andral* into the pathological phenomena afforded by seventy-five cases of paralysis in which the apoplectic effusion was limited to one or other of these bodies, does not afford the least countenance to any such doctrine. And it is affirmed by Longet, that injury or removal of the Corpus Striatum of one side did not, in his experiments, affect the posterior more than the anterior limb; nor could he detect any difference in the condition of these limbs after the removal of the Thalamus. — Turck† gives four cases of apoplexy or ramollissement of the Brain, in which with either permanent or transient hemiplegia there was intense and permanent anæsthesia of the same side of the body. The whole of the Cerebrum was sound, except in all cases the external part of one Optic Thalamus, where was a lesion of the Cerebral substance of considerable length, though not in most instances extending before or behind the Optic Thalamus.‡

520. In employing the information derived from the foregoing sources, as a guide in the inquiry into the part performed by the Sensory Ganglia in the ordinary operations of the Cerebro-Spinal system, we have to distinguish, as in the case of the Spinal Cord, between their operation as independent centres, and their action in subservience to the Cerebrum, which is superposed upon them.—We have seen reason to conclude that, in their former capacity, they are to be regarded as the true seat of *Sensation* (*i.e.* the material instruments through which the consciousness becomes affected by external impressions), and as the instrument, in virtue of their own 'reflex' power, of that class of Instinctive or Automatic movements, which require to be prompted and guided by sensations, and which cannot, therefore, be referred to the excito-motor group. But although it is sufficiently obvious that such movements constitute the highest manifestations of Animal life in the Invertebrata generally, and that they are but little modified by any higher principle of action even in the lower Vertebrata, yet it is no less obvious that in adult Man, in whom the Intelligence and Will are fully developed, we have comparatively little evidence of this independent reflex action of the Sensory Ganglia:—all those automatic actions which are *immediately* necessary for the maintenance of his Organic life, being provided-for by the excito-motor portion of the apparatus, so that although sensation ordinarily accompanies most of them, it is not essential to them; whilst those which are necessary to provide more *remotely* for its requirements, are for the most part committed to the guidance of his Reason. For the impressions which have been brought by the afferent nerves to his Sensorium, and which have there produced sensations, do not in general react at once upon the motor apparatus (as they do in those animals in which the Sensory Ganglia are the *highest*

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* "Clinique Médicale," tom. ii. p. 664 *et seq.*

† "Wiener Sitzungsberichte," xxxvi., 1859, p. 191.

‡ See Henle and Meissner, 1859, p. 517.

of the nervous centres), but usually transmit their influence upwards to the Cerebrum, through whose instrumentality they give rise to ideas and reasoning processes, which operate upon the motor apparatus either emotionally or volitionally. And it is for the most part only when this upward transmission is checked, either by the non-development or the functional inactivity of the Cerebrum, or by its complete occupation in some other train of action,—or, on the other hand, when the reflex action of the Sensory ganglia is called into play with unusual potency,—that we have any manifestations of the *sensori-motor* or *consensual* mode of operation in Man, that are at all comparable in variety or importance to those instinctive acts which are so remarkable in the lower animals (§ 430).

521. Still, sufficient evidence of the existence of this class of reflex movements may be drawn from observation of the actions of Man in his ordinary condition; examples of it being furnished (as we have seen) by the closure of the eyes to a dazzling light, the start caused by a loud and unexpected sound, and the sneezing excited by sensory impressions on the Schneiderian membrane or on the Retina. To these may be added the vomiting produced by various sensory impressions, as the sight of a loathsome object, a disagreeable smell, a nauseous taste, or that peculiar feeling of want of support which gives rise to 'sea-sickness,' especially when combined with the sight of continually-shifting lines and surfaces, which itself in many individuals disposes to the same state; the involuntary laughter which is excited by tickling, and also that which sometimes bursts-forth at the provocation of some sight or sound to which no ludicrous idea or emotion can be attached; the yawning which is excited by an internal sensation of uneasiness (usually arising from deficient respiration), or by the sight or sound of the act as performed by another; and those involuntary movements of the body and limbs, excited by uneasy sensations (probably muscular), which are commonly designated as 'the fidgets.' When the reflex activity of the Sensory ganglia is more strongly excited, in consequence either of an unusual potency of the sensory impressions, or of an unusual excitability of this part of the nervous centres, a much greater variety of sensori-motor actions is witnessed. The powerful involuntary contraction of the orbicularis and of the muscles which roll the eyeball upwards and inwards, in cases of excessive irritability of the retina (§ 505), is one of the best examples of this kind; but another very curious illustration is afforded by the involuntary abridgment of the excito-motor actions of respiration, when the performance of these is attended with pain,—the dependence of this abridgment upon the direct stimulus of sensation, rather than upon voluntary restraint, being obvious from the fact that it often presents itself on *one* side only, a limitation which the Will cannot imitate. Again, there are certain Convulsive disorders which appear to depend upon an undue excitability of these centres, the paroxysms being excited by impressions which act through the organs of sense, and are not thus operative unless the patient be conscious of them; thus in Hydrophobia, we observe the immediate influence of the sight, sound, or contact, of liquids, or of the slightest currents of air, in exciting muscular contractions; and in many Hysteric subjects, the sight of a paroxysm in another individual is the most certain means of its induction in themselves. A

remarkable case of this general exaltation of purely sensorial excitability has been recorded by Dr. Cowan; who gives the following account of its phenomena, which can scarcely be referred to any other than this category. "The shadow of a bird crossing the window, though the blind and bed-curtains are closed, the displacement of the smallest portion of the wick of a candle, the slightest changes in the firelight, induce a sudden jerking of the spinal muscles, extending to the arms and legs when violent, and this without the slightest mental emotion of any kind beyond a consciousness of the movement. At times the vocal organs are implicated, and a slight cry, quite involuntary, takes place. At these periods she is unusually susceptible of all noises, especially the least expected and least familiar. Movements in the next house inaudible to others, the slightest rattle in the lock of a door, tearing a morsel of paper, and a thousand little sources of sound not to be catalogued, induce results similar to those of visual impressions."*

522. It is, however, when the Cerebrum is not in a state which renders it capable of receiving and acting-upon Sensorial impressions, that we find the independent reflex activity of the Sensory ganglia most strikingly displayed. Thus in the Infant, for some time after its birth, it is obvious to an attentive observer, that a large part of its movements are directly prompted by sensations to which it can as yet attach no distinct ideas, and that they do not proceed from that *purposive* impulse which is essential to render them voluntary. This is well seen in the efforts which it makes to find the nipple with its lips; being probably guided thereto at first by the smell, but afterwards by the sight also; when the nipple has been found, the act of suction is purely excito-motor, as already explained. So in the Idiot whose brain has never attained its normal development, the influence of sensations in directly producing respondent movements is obvious to all who examine his actions with discrimination; and a remarkable case has been described,† in which an entire, though temporary suspension of Cerebral power, reducing the subject of it to the condition of one of the lowest Vertebrata, gave a very satisfactory proof of the independent activity of this division of the Encephalic centres.

523. But we do not require to go so far in search of characteristic examples of this kind of reflex action; since they are afforded by the performance of *habitual* movements, which are clearly under Sensorial guidance, when the Cerebrum is occupied in some train of action altogether disconnected with them. An individual who is subject to 'absence of mind,' may fall into a reverie whilst walking the streets; his attention may be entirely absorbed in his train of thought, and he may be utterly unconscious of any interruption in its continuity; and yet during the whole of that time his limbs shall have been in motion, carrying him along the accustomed path, whilst his vision shall have given to these movements the direction which is requisite to guide him along a particular line, or to move him out of it for the avoidance of obstacles. As already pointed-out (§ 498), there seems strong reason for regarding the ambulatory movements of the limbs as in themselves excito-motor; but the *guidance* of these movements by the visual sense indicates the participation of the Sensorium in this remarkable performance.—It has been maintained by some Metaphysicians and Physiologists, that these 'secon-

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* "Lancet," Oct. 4, 1845.

† Ibid., Nov. 15 and 29, 1845.

darily automatic' actions always continue to be voluntary, because their performance is originally due to a succession of volitional acts, and because, in any particular case, it is the Will which first excites them, whilst an exertion of the Will serves to check them at any time. But this doctrine involves the notion that the Will is in a state of pendulum-like oscillation between the train of thought and the train of movement; whereas nothing is more certain to the individual who is the subject of both, than that the former may be as uninterrupted as if the body were perfectly at rest, and his reverie were taking place in the quietude of his own study. And as it commonly happens that the direction taken is that in which the individual is most in the habit of walking, it will not unfrequently occur that if he had previously intended to pursue some other, he finds himself, when his reverie is at an end, in a locality which may be very remote from that towards which his walk was originally destined; which would not be the case, if his movements had been still under the purposive direction of the will. And although it is perfectly true that these movements can be at any time checked by an effort of the will, yet this does not really indicate that the will has been previously engaged in sustaining them; since, for the will to act upon them at all, the *attention* must be recalled to them, and the Cerebrum must be liberated from its previous self-occupation. And the gradual conversion of a volitional into an automatic train of movements, so that at last this train, once started, shall continue to run-down of itself, will be found to be less improbable than it would at first appear, when it comes to be understood that the mechanism of both sets of actions is essentially the same, and that they merely differ as regards the nature of the stimulus which originally excites them (§ 532). That the same automatic movements are not excited by the same sensations, when the Cerebrum is in its ordinary state of functional connection with the Sensorium, is a fact entirely in harmony with the principle already laid-down (§§ 439, 440). The complete occupation of the mind in other ways, as in close conversation or argument, or even (it may be) in the voluntary direction of some other train of muscular movements, is no less favourable than the state of reverie to that independent action of the Automatic centres which has been now described.

524. In the state of entire functional activity of the nervous centres of Man, however, there can be no doubt that the operation of the Sensory Ganglia is entirely subordinated to that of the Cerebrum; and that it furnishes an essential means of connection between the actions of the Cerebrum on the one hand, and those of the organs of Sense and Motion on the other, by the combination of which the Mind is brought into relation with the external world. For, in the first place, it may be affirmed with certainty that no mental action can be originally excited, save by the stimulus of Sensations; and it is the office of the Sensory ganglia to form these out of the impressions brought to them from the organs of sense, and to transmit such sensorial changes to the Cerebrum. But they have a no less important participation in the downward action of the Cerebrum upon the motor apparatus; for no voluntary action can be performed without the assistance of a *guiding sensation*, as was first prominently stated by Sir C. Bell.*—In the

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* See his chapter 'On the Nervous Circle which connects the Voluntary Muscles with the Brain,' in his work, "On the Nervous System of the Human Body."

majority of cases, the guiding or controlling sensation is derived from the muscles themselves, of whose condition we are rendered cognizant by the sensory nerves with which they are furnished; but there are certain cases in which it is ordinarily derived from one of the special senses, and in which the 'muscular sense' can only imperfectly supply the deficiency of such guidance; whilst, again, if the 'muscular sense' be deficient, one of the special senses may supply the requisite information. The proof of this necessity is furnished by the *entire impossibility of making or sustaining voluntary efforts, without a guiding sensation of some kind.* Thus, in complete anæsthesia of the lower extremities, without loss of muscular power, the patient is as completely unable to walk as if the motor nerves had also been paralyzed, unless the deficient sensorial guidance be replaced by some other; and in similar affections of the upper extremities, there is a like inability to raise the limb or to sustain a weight. But in such cases, the deficiency of the 'muscular sense' may be made good by the visual; thus, the patient who cannot feel either the contact of his foot with the ground, or the muscular effort he is making, can manage to stand and walk by *looking* at his limbs; and the woman who cannot feel the pressure of her child upon her arms, can yet sustain it so long as she keeps her eyes fixed upon it, but no longer,—the muscles ceasing to contract, and the limb dropping powerless, the moment that the eyes are withdrawn from it. Thus it is, too, that when we are about to make a muscular effort, the amount of force which we put-forth is governed by the mental conception of that which will be required, as indicated by the experience of former sensations; just as the contractions of the muscles of vocalization are regulated by the conception of the sound to be produced. Hence if the weight be unknown to us, and it prove either much heavier or much lighter than was expected, we find that we have put-forth too little or too great a muscular effort.

525. There are two groups of muscular actions, however, which, although no less voluntary in their character than the foregoing, are yet habitually guided by other sensations than those derived from the muscles themselves. These are, the movements of the *Eyeball*, and those of the *Vocal apparatus.*—The former are directed by the visual sense,* by which the action of the muscles is guided and controlled, in the same manner as that of other muscles is directed by their own 'muscular sense'; and hence it happens that, when we close our eyes, we cannot move them in any required direction without an effort that strongly calls-forth the muscular sense, by which the action is then guided. In persons who have become blind after having once enjoyed sight, an association is formed by habit between the muscular sense and the contractile action, that enables the former to serve as the guide after the loss of the visual sense; but in those who are born *perfectly* blind, or who have become so in early infancy, this association is never formed, and the eyes of such persons exhibit a continual indeterminate movement, and cannot by any amount of effort be steadily fixed in one spot, or be turned in any definite direction. A very small amount of the visual sense, however, such as serves merely to indicate the direction of light,

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* See Dr. Alison's Memoir on the 'Anatomical and Physiological Inferences from the Study of the Nerves of the Orbit,' in "Trans. of Roy. Soc. of Edinb.," vol. xv.

is sufficient for the government of the movements of the eyeball.—In the production of vocal sounds, again, that nice adjustment of the muscles of the Larynx, which is requisite to the giving-forth of determinate tones, is ordinarily directed by the auditory sense: being learned in the first instance under the guidance of the sounds actually produced; but being subsequently effected voluntarily, in accordance with the mental conception (a sort of inward sensation) of the tone to be uttered, which conception cannot be formed, unless the sense of hearing has previously brought similar tones to the mind. Hence it is that persons who are born *deaf*, are also *dumb*. They may have no malformation of the organs of speech; but they are incapable of uttering distinct vocal sounds or musical tones, because they have not the guiding conception, or recalled sensation, of the nature of these. By long training, however, and by imitative efforts directed by muscular sensations in the larynx itself, some persons thus circumstanced have acquired the power of speech; but the want of a sufficiently definite control over the vocal muscles is always very evident in their use of the organ.—It is very rarely that a person who has once enjoyed the sense of hearing, afterwards become so *completely* deaf, as to lose all auditory control over his vocal organs. An example of this kind, however, has been communicated to the public by a well-known author, as having occurred in himself; and the record of his experiences* contains many points of much interest. The deafness was the result of an accident occurring in childhood, which left him for some time in a state of extreme debility; and when he made the attempt to speak, it was with considerable pain in the vocal organs. This pain probably resulted from the unaccustomed effort which it was necessary to make, when the usual guidance was wanting; being analogous to the uneasiness which we experience, when we attempt to move our eyes with the lids closed. His voice at that time is described as being very similar to that of a person born deaf-and-dumb, but who has been taught to speak. With the uneasiness in the use of the vocal organs, was associated an extreme mental indisposition to their employment; and thus, for some years, the voice was very little exercised. Circumstances afterwards forced it, however, into constant employment; and great improvement subsequently took place in the power of vocalization, evidently by attention to the indications of the muscular sense. It is a curious circumstance fully confirming this view, that the words which had been in use previously to the supervention of the deafness, were still pronounced (such of them, at least, as were kept in employment) as they had been in childhood; the muscular movements concerned in their articulation having still been guided by the original auditory conception, in spite of the knowledge derived from the information of others that such pronunciation was erroneous. On the other hand, all the words subsequently learned were pronounced according to their spelling; the acquired associations between the muscular sensations and the written signs being in this case the obvious guide.

526. It is through the 'muscular sense,' in combination with the visual and tactile, that those movements are regulated which are concerned alike in ordinary progression, and in the maintenance of the

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* See the "Lost Senses," by Dr. Kitto; vol. i., chapters 2 and 3.

equilibrium of the body. That the visual sense has, in most persons, a large share in this regulation, is evident from the simple fact, that no one who has not been accustomed to the deprivation of it, can continue to walk straight-forwards, when blind-folded, or in absolute darkness, towards any point in the direction of which he may have been at first guided. But the blind man, who has been accustomed to rely exclusively upon his muscular sense, has no difficulty in keeping to a straight path; and moves onwards with a confidence which is in remarkable contrast with the gait of a man who has been deprived of sight for the occasion only. In fact, as Mr. Mayo has well remarked,* in our ordinary movements, "we lean upon our eyesight as upon crutches."—When our vision, however, instead of aiding and guiding us, brings to the mind sensations of an antagonistic character, our movements become uncertain, from the loss of that power of guidance and control over them, which the harmony of the two sensations usually gives. Thus a person unaccustomed to look down heights, *feels* insecure at the top of a tower or a precipice, although he *knows* that his body is properly supported; for the void which he sees below him contradicts (so to speak) the tactile sensations by which he is made conscious of the due equilibrium of his body. So, again, although any one can walk along a narrow plank, which forms part of the floor of a room, or which is elevated but a little above it, without the least difficulty, and even without any consciousness of effort, if that plank be laid across a chasm, the bottom of which is so far removed from the eye that the visual sense gives no assistance, even those who have braced their nerves against all emotional distraction, feel that an effort is requisite to maintain the equilibrium during their passage over it; that effort being aided by the withdrawal of the eyes from the abyss below, and the fixation of them on a point beyond, which at the same time helps to give steadiness to the movements, and distracts the mind from the sense of its danger. The degree in which the 'muscular sense' is alone sufficient for the guidance of such movements, when the mind has no consciousness of the danger, and when the visual sense neither affords aid nor contributes to distract the attention, is remarkably illustrated by the phenomena of Somnambulism; for the sleep-walker traverses, without the least hesitation, the narrow parapet of a house, and crosses narrow and insecure planks, clambers roofs, &c., under circumstances that clearly indicate the nature of the guidance by which he is directed.—The dependence of our ordinary power of maintaining our equilibrium, upon the combination of the guiding sensations derived through the sight and the touch, is further well illustrated, as Mr. Mayo has pointed-out (loc. cit.), by what happens to a landsman on first going to sea. "It is long before the passenger acquires his 'sea-legs.' At first, as the ship moves, he can hardly keep his feet; the shifting lines of the vessel and surface of the water unsettle his visual stability; the different inclinations of the planks he stands-on, his muscular sense. In a short time, he learns to disregard the shifting images and changing motions, or acquires facility in adapting himself (like one on horseback) to the different alterations in the line of direction in his frame." And when a person who has thus learned by habit to maintain his equilibrium on a shifting surface, first treads upon firm ground, he feels himself almost as much at fault as he did when he first went to sea: and it is only after being some time on shore, that he is able to resume his original manner of walking. Indeed, most of those who spend the greater part of their time at sea, acquire a peculiar gait, which becomes so habitual to them, that they are never able to throw it off.

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* "Outlines of Physiology," 3rd edit., p. 355.

527. But further, there is very strong physiological evidence, that the Sensory Ganglia are not merely the instruments whereby our voluntary movements are directed and controlled, in virtue of the guiding sensations which they furnish, but that they are actually the immediate centres of the motor influence which excites muscular contractions, in obedience to impulses transmitted downwards from the Cerebrum. It has usually been considered that the Cerebrum acts directly upon the muscles, in virtue of a direct continuity of nerve-fibres from the grey matter of its convolutions, *through* the Corpora Striata, the motor tract of the Medulla Oblongata, the anterior portion of the Spinal Cord, and the anterior roots of the nerves; and that in the performance of any voluntary movement, the Will determines the motor force to the muscle or set of muscles by whose instrumentality it may be produced. To this doctrine, however, the anatomical facts already stated constitute a very serious objection; for the motor tract cannot be stated with certainty to have any higher origin than the Corpora Striata; and it is impossible to imagine that the fibres which converge towards the surface of these bodies from all parts of the Cerebrum, can be so closely compacted-together as to be included in the motor columns of the Spinal Axis. The fact would rather seem to be, that these converging fibres bear the same kind of anatomical relation to the Corpora Striata and the other Sensorial centres of motor power, as do the fibres of the afferent nerves which proceed to them from the Retina, the Schneiderian membrane, and other peripheral expansions of nervous matter; and hence we might infer that the nerve-force generated in the convolutions, instead of acting *immediately* on the motor nerves, is first directed towards the Automatic centres, and excites the same kind of motor response in them, as would be given to an impression transmitted to them through a sensory nerve. We shall find that such a view of the structural arrangements of these parts is in remarkable accordance with their functional relations, as indicated by a careful analysis of the mechanism of what is commonly regarded as 'voluntary' movement. The Cerebrum may thus call the motor apparatus into action, as the instrument either of *ideas*, of *emotions*, or of *volitional determinations;* but we must limit our present examination to *voluntary* movements alone, these having been usually regarded as in such complete antagonism to those of the automatic group, that even separate sets of nerve-fibres have been thought requisite, to account for the transmission of these two distinct orders of motor impulses to the muscles.

528. Now in the first place, it may be asserted with some confidence, that no effort of the Will *can* exert that direct influence on the muscles, which our ordinary phraseology, and even the language of scientific reasoners, would seem to imply; but, on the other hand, that the Will is solely concerned in determining the *result;* the selection and combination of muscular movements required to bring about this result, *not* being

effected by the Will, but by some intermediate agency. If it were otherwise, we should be dependent upon anatomical knowledge for our power of performing the simplest movement of the body; whereas we find the fact to be, that the man who has not the least idea of the mechanism of muscular action, can acquire as complete a command over his movements, and can adapt them as perfectly to the desired end, as the most accomplished anatomist could do. Further, we cannot, by any exertion of the will, single-out a particular muscle, and throw it into contraction by itself, unless that muscle be one which is alone concerned in an action that we can voluntarily perform; and even then we single it out by *willing* the action. Thus we can put the *levator palpebræ* in action by itself; but this we do, not by any conscious determination of power to the muscle itself, but by *willing* to raise the eyelids; and it is only by our anatomical knowledge that we know that but a single muscle is concerned in this movement. So far as our own consciousness can inform us, there is no difference between the mechanism of this action and that of the flexion of the knee- or elbow-joint; and yet in these latter movements, several muscles are concerned, not one of which can be singled-out by an effort of the will, and thrown into action separately from the rest.—The idea that the will is *directly* exerted upon the muscles called into action to produce a particular movement, may seem to derive some support from the sense of *muscular effort* of which we are conscious in making the exertion, and which we refer to the muscles which are concerned in it; but this sense of effort is nothing else than the 'muscular sense' already alluded-to, which has its origin in the state of tension of the muscles, and which is no more an indication of *mental* effort directed to them, than the sensation of light or sound is an indication of a determination of voluntary power to the eyes or ears.

529. There are two cases, already referred-to under another head, in which it is very easy to show that the Will is concerned with the result alone, and is not directly exerted upon the instruments by which that result is brought-about: these are, the movements of the Eyes, and the production of Vocal tones. In neither of them are we conscious of any effort in the muscular apparatus, unless the contraction be carried beyond its accustomed extent; the ordinary movements being governed, as already remarked, not by the muscular sense, but by the visual and auditory senses respectively.—Nothing can be more simple, to all appearance, than the act of turning the eyes upwards or downwards, to one side or the other, in obedience to a determination of the Will; and yet the Will does not impress such a determination upon the muscles. That which the Will really does, is to cause the eyeballs to roll in a given direction, in accordance with a visual sensation; and it is only *when there is an object* towards which the eyes can be turned, that we can move them with our usual facility. When the eyelids are closed, and we attempt to roll the globes upwards or downwards, to one side or to the other, we feel that we can do so but very imperfectly, and with a sense of effort referred to the muscles themselves,—this sense being the result of the state of tension in which the muscles are placed by the effort to move the eyes without the guiding visual sensation. Now, on the other hand, the Will may determine to fix the eyes upon an object; and yet this very fixation may be only attainable by a muscular movement, which movement is

directly excited by the visual sense, without any exertion of voluntary power over the muscles. Such is the case when we determinately look steadily at an object, whilst we move the head horizontally from side to side; for the eyeballs will then be moved in the contrary direction by a kind of instinctive effort of the external and internal recti, which tends to keep the retinæ in their first position, and to prevent the motion of the images over them. So, when we look steadily at an object, and incline the head towards either shoulder, the eyeballs are rotated upon their antero-posterior axis (probably by the agency of the oblique muscles) apparently with the very same purpose,—that of preventing the images from moving over the retinæ (see CHAP. XIII., Sect. 3). Now we cannot refuse to this rotation any of the attributes which really characterize the so-called voluntary movements; and yet we are not even informed by our own consciousness that such a movement is taking place, but know it only by observation of others, or by the reflection in a mirror.

530. The muscular contractions which are concerned in the production of Vocal tones, are, in like manner, always accounted voluntary; and yet it is easy to show that the Will has no direct power over the muscles of the larynx. For we cannot raise or depress the larynx as a whole, nor move the thyroid cartilage upon the cricoid, nor separate or approximate the arytenoid cartilages, nor extend or relax the vocal ligaments, by simply *willing* to do so, however strongly. Yet we can readily do any or all these things, by an act of the Will exerted for a specific purpose. We conceive of a tone *to be* produced, and we *will* to produce it; a certain combination of the muscular actions of the larynx then takes place, in most exact accordance with one another; and the predetermined tone is the result. This anticipated or conceived sensation is the guide to the muscular movements, when as yet the utterance of the voice has not taken place; but whilst we are in the act of speaking or singing, the contractile actions are regulated by the present sensations derived from the sounds as they are produced.—It can scarcely but be admitted, then, that the Will does *not* directly govern the movements of the Larynx; but that these movements are immediately dependent upon some other agency.

531. Now what is true of the two preceding classes of actions, is equally true of all the rest of the so-called *voluntary* movements; for in each of them the power of the Will is really limited to the determination of the result; and the production of that result is entirely dependent upon the concurrence of a 'guiding sensation,' which is usually furnished by the very muscles that are called into action. It is obvious, therefore, that we have to seek for some intermediate agency, which *executes* the actions *determined* by the Will; and when the facts and probabilities already stated are duly considered, they tend strongly in favour of the idea that even Voluntary movements are executed by the instrumentality of the Automatic apparatus, and that they differ only from the automatic or instinctive in the nature of the stimulus by which they are excited,—the determination of the Will here replacing, as the *exciting cause* of its action, the sensory impression which operates as such in the case of an instinctive movement, and which is still requisite for its guidance.

532. This view of the case derives a remarkable confirmation from the analysis of two classes of very familiar phenomena: the first consisting of cases in which movements that are ordinarily Automatic are per-

formed by Voluntary determination, or simply in respondence to an Idea; the second consisting of those in which movements originally Voluntary come by habit to be Automatically performed.—Of the first class, the act of Coughing is a good example. This action, which is ordinarily automatic, may also be excited by a voluntary determination; such a determination, however, is directed to the *result*, rather than exercised in singling-out the different movements and then combining them in the necessary sequence; and the Will thus seems obviously to take the place of the laryngeal or tracheal irritation, as the *primum mobile* of the series, which, in its actual performance, is as automatic in the latter case as in the former. So, again, we know that many of the automatic movements which have been already referred-to as examples of the sensori-motor group (§ 521), and which the Will cannot call-forth, may be performed in respondence to *ideas* or *conceptions*, which are Cerebral states that seem to recal the same condition of the Sensorium as that which was originally excited by the Sensory impression. Thus it is well known that the act of Vomiting may be induced by the *remembrance* of some loathsome object or nauseous taste, excited by some act of 'suggestion;' and the Author has known an instance in which a violent fit of sea-sickness was brought-on by the sight of a vessel tossed about at sea, which recalled the former experience of that state. So the Hydrophobic paroxysm may be excited by the mention of the *name* of water, which of course calls up the idea; and a tendency to yawn is in like manner frequently induced by looking at a picture of yawners, or by speaking of the act, or by voluntarily commencing the act which may then be automatically completed.—The automatic performance of actions which were originally voluntary has already been fully discussed (§ 523); and we have therefore only to remark here, that the fact very strongly supports the view now advanced, as to the *singleness* of the mechanism which serves as the instrument of both classes of actions, and the essential uniformity of its operation in the two cases.—It would be difficult to explain either set of phenomena satisfactorily, on the hypothesis that there is a 'distinct system' of fibres for the volitional and for the automatic movements; since it is not readily to be conceived how a set of movements originally performed by the one can ever be transferred to the other; whilst, on the other hand, it is easy to understand how the same motorial action may be excited in the automatic centres, either by an *external* impression conveyed thither by an afferent nerve from a Sensory surface (as that of the irritation in the air-passages, which excites the act of coughing), or by a stimulus proceeding from the convoluted surface of the Cerebrum, and conveyed along those connecting fibres which Reil with great sagacity termed the 'nerves of the *internal* senses.'

533. To sum-up, then, we seem justified in concluding that the *Cranio-Spinal Axis* of Man and other Vertebrata,—consisting of the Sensory Ganglia, Medulla Oblongata, and Spinal Cord,—is (like the chain of cephalic and ventral ganglia of Articulata with which it is homologous) the immediate instrument of *all sensorial and motor changes;* that by its sole and independent action are produced all those movements which are ranked as *automatic* or *instinctive*, these being performed in respondence to external impressions which may or may not affect the consciousness;

but that when acting in subordination to the Cerebrum, the Cranio-Spinal Axis transmits upwards to it the influence of Sensorial changes, and receives from it the downward impulses, which it directs automatically into the appropriate channel for the execution of the movements which the Mind has directed. The number of purely-automatic actions diminishes in proportion to the development of the Cerebrum, and to the subjection of the Automatic apparatus to its control; but even in Man, those most closely connected with the maintenance of the organic functions, or most necessary for the conservation of the bodily structure, remain quite independent of any mental agency, and most of them do not require consciousness for their excitation. But if the activity of the Cerebrum be suspended or be otherwise directed, without any affection of the automatic apparatus, movements which have long been habitually performed in a particular sequence, may be kept-up, when the will has once set them in action, through the automatic mechanism alone; the impressional or sensational change produced by each action, supplying the stimulus which calls-forth the next.—It may further be concluded that the Sensory Ganglia, which are the instruments whereby we are rendered *conscious* of external impressions, are also the seat of those simple *feelings* of pleasure and pain which are immediately linked-on to that consciousness: for it can scarcely be doubted that such feelings must be associated with particular sensations, in animals that have no ganglionic centres above these; since we must otherwise regard the whole series of Invertebrated tribes as neither susceptible of enjoyment, nor capable of feeling pain or discomfort. And it likewise seems probable that the Sensory Ganglia are also the seat of those *perceptional* acts, which bring the consciousness into direct relation with the external object that aroused the sensation; since the recognition of *externality* seems evident in the actions of the tribes just referred-to.*

4. *Of the Cerebellum, and its Functions.*

534. The Cerebellum is an organ which, though confined to the Vertebrated sub-Kingdom, is yet in peculiarly-intimate relation with the Automatic apparatus. In that highest state of development which it presents in Man, we find it to consist of two *lateral* lobes or *hemispheres*, composed of nerve-fibres invested in a very peculiar manner by vesicular substance, and of a *central* lobe, also containing a combination of the vesicular and fibrous substances, which is known under the designation of the 'vermiform process.' The hemispheres are connected with each other not only by this central lobe, but also by the fibrous commissure which passes beneath the Medulla Oblongata, and is known as the 'Pons Varolii.' The commissural fibres form part of the 'Crura Cerebelli;' but another portion is formed by the strands which connect the Cerebellum with the anterior and posterior columns of the Spinal Cord and Medulla Oblongata (§ 475); and in addition to these, we find a fasciculus of fibres passing between the Cerebellum and the Corpora Quadrigemina,

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* It may here be remarked that the term Sensation is now understood to imply the simple consciousness of an impression, whilst Perception refers that impression to something out of the *ego*. For the production of a Sensation a conscious state of the mind is all that is required; but for the exercise of the Perceptive power a certain degree of *attention* is requisite.

the 'iter a cerebello ad testes.' The peduncle of its hemispheres on either side contains a mass of grey matter, the 'corpus rhomboideum,' or 'dentatum,' which seems to be a ganglionic centre for the fibres that pass upwards to it from the Spinal Cord. The Cerebellum has no direct connection with the Cerebrum, and its relations are entirely with the Cranio-Spinal Axis.

535. When we examine into the relative development of the Cerebellum in the different classes of Vertebrata, we find that it presents some very remarkable differences.* In its simpler forms, this organ is found to consist entirely of the representative of the *central* lobe of the Human Cerebellum, the hemispheres not making their appearance until we have ascended to the class of Birds. On ascending the scale of Mammiferous animals, on the other hand, we cannot but be struck with the rapid advance in the proportional size of the Cerebellum, which we observe as we rise from the lowest (which are surpassed in this respect by many Birds) towards Man, in whom it attains a development which appears enormous, even when contrasted with that of the Quadrumana. In proportion, in fact, as the extremities acquire the power of prehension, and together with this a power of application to a great variety of purposes,—still more, in proportion as the animal becomes capable of maintaining the erect posture, in which a constant muscular exertion, consisting of a number of most elaborately-combined actions, is required,—do we find the size of the Cerebellum, and the complexity of its structure, undergoing a rapid increase. Thus, even between the Dog and the Bear there is a marked difference; the latter being capable of remaining for some time in the erect posture, and often spontaneously assuming it; whilst to the former it is anything but natural. In the semi-erect Apes, again, there is a very great advance in the proportional size of the Cerebellum; and those which most approach Man in the tendency to preserve habitually the erect posture, also come nearest to him in the dimensions of this organ.—Thus on looking at the size of the Cerebellum, in relation to the general motor activity of the Vertebrated classes respectively, and especially taking into account the *variety* of their respective movements, and the number of separate muscular actions which are combined in each, we can scarcely help noticing that it is in the tribes which are most distinguished in these respects, that the largest Cerebellum is usually found. Now it is evident that Man, although far inferior to many of the lower animals in the power of performing various particular kinds of movement, far surpasses them all in the number and variety of the combinations which he is capable of executing, and in the complexity of the combinations themselves. Thus, if we attentively consider the act of *walking*, we shall find that there is scarcely a muscle of the trunk or extremities which is not actively concerned in it; some being engaged in performing the necessary movements, and others in maintaining the equilibrium of the body which is disturbed by them. On the other hand, in the Horse or Camel, the muscular movements are individually numerous, but they do not require nearly the same

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* See "Princ. of Comp. Phys.," § 685.—Fuller information upon this point will be found in M. Serres' "Anat. Comp. du Cerveau," and M. Leuret's "Anat. Comp. du Système Nerveux."—For a general discussion of the evidence afforded by Comparative Anatomy in regard to the functions of the Cerebellum, see the "Brit. and For. Med. Rev.," vol. xxii. pp. 535–541.

perfect co-ordination. And in the Bird, the number of muscles employed in the movements of flight, and in directing the course of these, is really comparatively small; as may at once be perceived, by comparing the rigidity of the skeleton of the trunk of the Bird with that of Man, and by remembering the almost complete inactivity of the lower extremities during the active condition of the upper. In fact, the motions of the wings are so simple and regular, as to suggest the idea, that, as in Insects, their character is more reflex than voluntary:—an idea which is supported by the length of time during which they can be kept-up without apparent fatigue, and also by the important facts already mentioned (§ 512), which experimental research has disclosed.

536. We have next to inquire what evidence can be drawn from Experimental investigations on the same subject: and in reference to this it is desirable to remark, in the first place, that the experimental mode of inquiry is perhaps more applicable to this organ than to other parts of the Encephalon; inasmuch as it can be altogether removed with little disturbance of the actions immediately essential to life, the animals soon recovering from the shock of the operation, and seeming but little affected except in some easily-recognized particulars. The principal experimenters upon this subject have been Rolando, Flourens, Magendie, Hertwig, Longet, Schiff, Brown-Séquard, and Wagner. It is not to be expected, that there should be an exact conformity among the results obtained by all. Every one who has been engaged in physiological experiments is aware of the amount of difference caused by very minute variations in their circumstances; in no department of inquiry is this more the case, than in regard to the Nervous System; and such differences are yet more likely to occur in experiments made upon its centres, than in those which concern its trunks.—The investigations of Flourens* seem the most clear and decisive in their results; and of these we shall accordingly take a general survey. He found that, when the Cerebellum was mechanically injured, the animals gave no signs of sensibility, nor were they affected with convulsions. When the Cerebellum was being removed by successive slices, the animals became restless, and their movements were irregular; and by the time that the last portion of the organ was cut-away, the animals had entirely lost the power of springing, flying, walking, standing, and preserving their equilibrium,—in short, of performing any combined muscular movements, which are not of a simply-reflex character. When an animal in this state was laid upon the back, it could not recover its former posture; but it fluttered its wings and did not lie in a state of stupor. When placed in the erect position, it staggered and fell like a drunken man,—not, however, without making efforts to maintain its balance. When threatened with a blow, it evidently saw it, and endeavoured to avoid it. It did not seem that the animal had in any degree lost voluntary power over its several muscles; nor did sensation appear to be impaired. The faculty of *combining* the actions of the muscles in groups, however, was completely destroyed; except so far as those actions (like that of Respiration) were dependent only upon the reflex function of the Spinal Cord. The experiments afforded the same results, when made upon each class of Vertebrated animals; and they have been since repeated, with nearly corresponding effects, by Bouillaud, Hertwig, and by many

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* "Recherches Expérim. sur les Propriétés et les Fonctions du Système Nerveux."

other experimenters.[*] Wagner found that the chief symptoms produced in Pigeons from which he had removed the whole or the greater part of the Cerebellum were—1. A remarkable tendency on the part of the animal to throw itself on one side, and to keep the legs completely extended, with an indisposition to move them, though it was still evidently capable of flexing them by an effort of the will. 2. Torsion of the head on the neck. 3. Persistent trembling of the muscles of the body generally, resembling *paralysis agitans.* 4. Vomiting, frequently accompanied by liquid alvine evacuations; and 5. The animals became thinner, the feathers fell off, and the temperature was much depressed. No symptoms were observed having reference to the generative organs. The perception of sensations and the performance of psychical operations appeared to be perfect; and though the voluntary control over the muscles was somewhat impaired, it was manifestly not altogether lost. Hertwig, and especially Dalton,[†] have moreover shown that in pigeons a very considerable portion (two-thirds) of the Cerebellum may be removed with so little disturbance of the voluntary movements, that after a few days the effects were scarcely, if at all, perceptible. Lussana observes that the results of irritation of the Cerebellum are usually vomiting, cephalalgia, convulsions and affections of the pupil, strabismus, amblyopia, &c.; and he believes that in every case of extensive disease of the Cerebellum there are concurrent symptoms of disorder of the muscular movements, indicative of defect or absence of the "muscular sense."

537. It was further affirmed by Magendie, that the removal of the Cerebellum, or the infliction of a deep wound in its substance on both sides, occasions the animal to move *backwards* as if by an irresistible impulse; and this he attributed to the retrograde power of the Corpora Striata, which now acts without its due balance. That such a movement does *sometimes* present itself after such injuries as have been described, cannot be questioned, the fact having been confirmed by other experimenters; but it is a phenomenon of such rarity, that it cannot be rightly considered as having any direct dependence upon the injury of the Cerebellum, but must be rather set-down to some accidental complication or concurrent disturbance; more especially since, as already pointed-out (§ 533), the function attributed by Magendie to the Corpora Striata has no real existence.—But the results of section of one of the Crura Cerebelli, which were first obtained by Magendie, are much more constant; for the performance of this operation causes the animal to fall-over upon one side, and to continue *rolling upon its longitudinal axis*, even as fast (in some instances) as sixty times in a minute, the movement going-on for many days without intermission. There is a remarkable difference in the statements of different experimenters, however, as regards the direction of this rolling movement; for whilst Magendie and Müller affirm that it
-place *towards* the injured side, Longet and Lafargue assert that it
-place *from* the injured side towards the opposite side. This dis-
cy appears, from the experiments of Schiff,[‡] to be due to a difference
locality of the section; for he states that if the peduncle be divided

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[*] See Wagner, in Brown-Séquard's "Journal de la Physiol.," 1861, pp. 255 and 404; Lussana in idem, 1862, p. 418, 1863, p. 170; MM. Leven and Ollivier, "Archiv. Gén. de Méd.," Nov. and Dec. 1862; Dalton, "American Journal of Med. Science," 1861, vol. xli. p. 83; Brown-Séquard, "Central Nervous System," 1860.

[†] "American Journ. of Med. Sciences," 1861, vol. xli. p. 83.

[‡] "De vi motoriâ baseos encephali inquisitiones experimentales;" Bockenhemii, 1845.

from behind, the animal turns *towards* the side on which the section is made; whilst if the section be made *in front*, the animal turns *from* that side towards the opposite one. This difference is explained by Longet, by the difference in the course of the anterior and posterior fibres of the peduncles: for according to him, the former communicate with the decussating, and the latter with the non-decussating portion of the motor tract; so that, when the former are injured, the animal loses control over the muscles of the opposite side, and when the latter, over the muscles of the same side. This rolling movement is attributed by some to the continued activity of the muscles on one side, now unbalanced by that of the muscles on the other; but if such were the case, as Longet justly remarks, it ought to occur more frequently than it does in cases of ordinary hemiplegia; and, according to that experimenter, observation shows that it rather depends on a *twisting* movement of the spinal column, especially affecting its anterior portion, and dragging the posterior (as it were) after it.* Thus M. Brown-Séquard,† who has shown that similar rolling movements may be produced by lesions of other parts of the nervous centres, as the Spinal Cord, Medulla Oblongata, and Pons, observes that the movements do not resemble those effected by voluntary muscles; but that, in consequence of the tonic contraction into which some muscles are thrown, the trunk and neck of the animal are twisted, as far as the bones will permit, into the form of a corkscrew. He attributes the phenomena in question, which the animal evidently endeavours to check, to the irritation of a peculiar set of nerve-fibres not usually employed by the will, the division of which does not cause paralysis, though they may serve as the conductors of powerful motor impulses to special groups of muscles. MM. Leven and Ollivier, operating on guinea-pigs, found that pricking the Cerebellum produced well-marked movements of rotation, usually proceeding from the side injured towards the opposite side. They did not observe any disorders of the alimentary canal similar to those noticed by Wagner and others, after ablation of portions of the Cerebellum.

538. The information supplied by Pathological phenomena, when interpreted with the cautions formerly referred-to, is found on the whole to coincide with that obtained from experiment. In the first place, it fully supports the conclusion, that the Cerebellum is not in any way the instrument of *psychical* operations. Inflammation of the membranes covering it, if confined to that part, does not produce delirium; and its almost complete destruction by gradual softening does not appear necessarily to involve loss of intellectual power. "But," remarks Andral, "whilst the changes of intelligence were variable, inconstant, and of little importance, the lesions of motion, on the contrary, were observed in all the cases [of softening] except one; and in this it is not quite certain that motion was not interfered with." Yet the result of Andral's analysis of as many as ninety-three cases of disease of the Cerebellum,‡ is not favourable to the doctrine to which the results of experiments seem to point: but, as it has been justly remarked by Longet, the effects of disease are only partly comparable to those of experiment; since in a large proportion of chronic disorders, the changes consist in the formation of a new product, such as a tubercular or cancerous deposit, or a cyst of some kind, the gradual

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* See his "Traité de Physiologie," tom. ii. p. 408, 1860.

† "Central Nervous System," 1860, p. 193.

‡ See his "Clinique Médicale," 2ème édit. tom. v. p. 735.

development of which is quite consistent with the continued functional activity of the organ, as we see by parallel phenomena elsewhere; whilst in those instances in which hæmorrhage occurs, this usually occasions either complete apoplexy or local paralysis, by its effects upon other organs. Still, several cases of chronic disease of the Cerebellum have been observed, in which *unsteadiness of gait*, without paralysis, or only giving-place to paralysis at last on the occurrence of hæmorrhage, was a very marked symptom;* and these afford a strong confirmation of the doctrine based on the experimental researches already referred-to. In a few cases in which both lobes of the Cerebellum have been seriously affected, the tendency to retrograde movement has been observed; and instances are also on record, of the occurrence of rotatory movement, which has been found to be connected with lesion of the Crus Cerebelli on the same side.† So far as they can be relied-on, therefore, the results of the three methods of investigation bear a very close correspondence; and it can scarcely be doubted that they afford us a near approximation to truth.

539. It must not be allowed to pass unnoticed, that some Physiologists (as Foville, Pinel-Grandchamp, and Dugès) have regarded the Cerebellum as the centre of common Sensation; chiefly on the ground of its connection with the posterior columns of the Spinal Cord, and of the manifestations of pain which are called-forth by touching the Restiform columns. Although these facts may lead us to admit that the Cerebellum is connected with the sensorial centres, and even that it is itself *a* seat of sensibility, yet it is impossible to regard it as the exclusive seat of sensibility, consistently with the facts with which experiment and pathological observation supply us; since neither the removal of the entire organ by operation, nor its complete destruction by disease,‡ have been found to involve any loss of the ordinary sensorial powers.—There would seem much more probability in the idea, that it is the special seat of the 'muscular sense,' which has so important a share in the guidance of the co-ordinated movements (§ 524); and this notion derives confirmation from the marked structural connection which exists between the Cerebellum and the Optic Ganglia (corpora quadrigemina), the purpose of which may be not unfairly surmised to be, to communicate the guidance of the *visual* sense to the organ by which the co-ordination of motions is effected, in the same manner as the impressions appertaining to the 'muscular sense' are transmitted upwards by the Restiform columns.§ The chief objection to such

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* Two such cases are recorded by Mr. Dunn in the "Med.-Chir. Trans.," vol. xxxii., and another by Dr. Cowan in the "Prov. Med. and Surg. Journ.," April 16, 1845; and the Author has been made acquainted with several others, by gentlemen under whose cognizance they have fallen.

† A collection of such cases has been made by Dr. Paget, in his paper on 'Morbid Rhythmical Movements,' in the "Edinb. Med. and Surg. Journal," 1847, vol. lxvi case once fell within the Author's knowledge, in which a state of this kind, that lasted for some hours, appeared to depend upon an attack of Indigestion; the symptoms being completely relieved by vomiting, and no further indication of Encephalic disorder manifesting itself.

‡ See the well-known case recorded by Combetti, in the "Revue Médicale," tom. ii. p. 57.

§ This view, suggested many years since by the Author, has been recently supported in the able papers by M. Ph. Lussana in the "Journal de la Physiologie," tom. v. 1862, p. 484, and tom. vi. p. 169; and also by Mr. Robert Dunn, in his "Essay on Physiological Psychology" (London, 1858), who also places the centre of the muscular sense in the corpus rhomboidale of the Cerebellum.

a view, would seem to lie in the strong similarity between the 'muscular' sense and 'common' or 'tactile' sensation, which makes it difficult to conceive that they should have different seats in the *Sensorium commune*. But this difficulty is diminished if not removed by the reflection, that the Restiform columns appear to have the same endowments as the remainder of the Sensory tract derived from the posterior columns of the Spinal Cord; and that no explanation can be given of their extreme sensitiveness to impressions (as shown by experiment), unless it be admitted that the organ in which they terminate is itself a centre of a form of sensation closely allied to that of the common or tactile kind. Possibly, however, the true termination of these fibres is in the 'corpus dentatum' of the Crura Cerebelli; and the Cerebellum may re-act upon impressions thence transmitted to it, without being itself the instrument of communicating such impressions to the consciousness.*

540. We have now to examine, however, another doctrine regarding the functions of the Cerebellum, which was first propounded by Gall, and which is supported by the Phrenological school of physiologists. This doctrine, that the Cerebellum is the organ of the sexual instinct, is not altogether compatible with the other; and by some it has been held in combination with it. The greater number of Phrenologists, however, regard this instinct as the *exclusive* function of the Cerebellum; and assert that they can judge of its intensity, by the degree of development of the organ. We shall now examine the evidence in support of this position, afforded by the three methods of inquiry which have been already indicated.—In the first place it may be remarked, that the sexual propensity is very closely connected with various Emotional states of mind, to which 'organs' are assigned by Phrenologists, and of which

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* M Brown-Séquard ("Journ. de la Physiol.," vol. i. 1858, p. 535) and Wagner (Op. cit.) have arrived at almost purely negative results in regard to the function of the Cerebellum. The former experimenter holds that this organ is not a nervous centre for sensitive impressions nor for consciousness, nor is it even a part through which the conductors of motion or of sensation pass; for he believes that no idea, emotion, or voluntary act is suppressed as a consequence of lesion of its structure. Hence he maintains, that it is not a centre for the faculty of balancing or co-ordination of the symmetrical movements of the body, and that when paralysis is observed after lesion of its structure, it is occasioned (when the paralysis is on the opposite side of the body) by concurrent lesions of other parts, as the Pons Varolii, the Medulla Oblongata, or the Cerebral peduncles; whilst, when the paralysis is on the same side, it is *usually* due to *irritation* of certain parts of the Cerebellum reacting on other parts of the Encephalon, though even from this cause the paralysis may sometimes occur on the opposite side. Though he does not admit it to be a centre for auditory or visual impressions, he acknowledges that it has a special influence on vision, having collected 60 cases of amaurosis accompanying disease of its structure. He has, in a more recent paper ("Journ. de la Phys.," 1862, tom. v. p. 486), attributed the various effects of Cerebellar lesion, as amaurosis, vomiting, cephalalgia, dilatation of the pupil, general or local convulsive movements, epilepsy, hemiplegia, general debility and disordered movements, contraction of particular muscles, strabismus, hyperæsthesia, noises in the ears, and exaggeration of the sexual desire, to *irritation* of the Cerebellum, and not to *loss of function*. He compares these effects with those produced by worms in the intestines. Wagner believes that this organ may become the *point de départ* of a direct (not reflex) irritation for certain organic muscles, as for those of the abdominal viscera, generative organs, and also, probably, for the heart. Schiff, at the conclusion of his section on the Cerebellum, states simply that "the functions of this organ are still unknown;" whilst Lussana, in the essay already quoted, finishes by observing that the *muscular sense* and the *erotic sense* are the two essential functions of the Cerebellum.

the Cerebellum is universally admitted to be the seat; such for instance as 'love of offspring,' 'adhesiveness,' and (in the lower animals more particularly) 'combativeness;' whilst in Man it has a continual operation upon the reasoning faculties and the Will. Yet the anatomical connections of the Cerebellum are peculiarly unfavourable to any such influence; these being, as we have seen, rather with the lower than with the higher portion of the Cerebro-spinal axis.—Again, the results of fair observation as to the comparative size of the Cerebellum in different animals, can scarcely be regarded as otherwise than very unfavourable to the doctrine in question.[*]—It is asserted, however, that the results of observation in Man lead to a positive conclusion, that the size of the Cerebellum is a measure of the intensity of the sexual instinct in the individual. This assertion has been met by the counter-statement of others, that no such relation exists. It is unfortunate that here, as in many other instances, each party has registered the observations favourable to its own views, rather than those of an opposite character; so that until some additional evidence of a less partial nature shall have been collected, we must consider the question as *sub judice*. It may be safely affirmed, however, that no evidence upon the affirmative side of this proposition has yet been adduced, which can be in the least degree satisfactory to the mind of any Anatomist who is competent to judge of its value. For nearly all the observations which have been paraded by Phrenologists in support of Gall's doctrine, have been based, *not* upon the actual *determination* of the size or weight of the Cerebellum in different individuals, but upon an *estimate* of its proportional development from the external conformation of the skull. Now any one who has even cursorily examined those principal types of cranial conformation which are characteristic of some of the chief subdivisions of the Human species, must perceive that there is a no less characteristic difference between these different types in the occipital, than there is in the frontal region. For whilst the occipital projection is much *greater* in the 'prognathous' skull than it is in the 'elliptical,' it is as much *less* in the 'pyramidal;' and thus while the first would be considered, according to phrenological rules, to hold a much larger Cerebellum, this organ in the latter would be regarded as necessarily very small. Now there is not only as much evidence of a strong development of the sexual propensity, in the characters and habits of the pyramidal-skulled Asiatics, as there is in regard to the elliptical-skulled Europeans, or the prognathous Negroes; but there is also anatomical evidence to show that *the size of the Cerebellum in the different races bears no relation whatever to the degree of projection of the occiput;* for the plane of this organ being somewhat oblique in the elliptical skull, is horizontal in the prognathous, and nearly vertical in the pyramidal, while the size and anatomical relations of the organ are not in the least degree affected by this difference in its position.[†]—Hence it may be safely affirmed, that no evidence with regard to the relation asserted to exist between the size of the Cerebellum and the intensity of the sexual propensity, has any value, save that which is drawn from the positive determination of the former by measure or weight.

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[*] See "Brit. and For. Medical Review," vol. xxii. pp. 535–541.

[†] The Author's statements on this point are based on the very decided assertions of his late friend Prof. Retzius of Stockholm, who paid special attention to this inquiry.

541. Among the arguments adduced by Gall and his followers in proof of the connection between the Cerebellum and the sexual instinct, is one which would deserve great attention, if the facts stated could be relied-on. It has been asserted, over and over again, that the Cerebellum, in animals which have been castrated when young, is much smaller than in those which have retained their virility,—being, in fact, *atrophied* from want of power to act. Now it is unfortunate that vague assertion, founded on estimates formed by the eye from the cranium alone, is all on which this position rests; and it will be presently shown how very liable to error such an estimate must be. The following is the result of a series of observations on this subject, suggested by M. Leuret,† and carried into effect by M. Lassaigne:—The *weight* of the Cerebellum, both absolutely and as compared with that of the Cerebrum, was adopted as the standard of comparison. This was ascertained in ten Stallions, of the ages of from nine to seventeen years; in twelve Mares, aged from seven to sixteen years; and in twenty-one Geldings, aged from seven to seventeen years. The average weight of the Cerebrum in the *Stallions* was 433 grammes; the greatest being 485 gr., and the least (which was in a horse ten years old) being 350 gr. The average weight of the Cerebellum was 61 gr.; the greatest being 65 gr., and the least 56 gr. The average proportion borne by the weight of the Cerebellum to that of the Cerebrum, was, therefore, 1 to 7·07; the highest (resulting from a very small Cerebrum) being 1 to 6·25; and the lowest (resulting from an unusually large Cerebrum) being 1 to 7·46. Throughout it might be observed, that the variation in the size of the Cerebellum was much less than in that of the Cerebrum.—In the twelve *Mares*, the average weight of the Cerebrum was 402 gr.; the highest being 432 gr., and the lowest 363 gr. That of the Cerebellum was 61 gr.; the highest being 66 gr. (which was in the individual with the smallest Cerebrum), and the lowest 58 gr. The average proportion of the weight of the Cerebellum to that of the Cerebrum was 1 to 6·59; the highest being 1 to 5·09, and the lowest 1 to 7. The proportion was, therefore, considerably higher in the perfect female, than in the perfect male.—In the twenty-one *Geldings*, the average weight of the Cerebrum was 419 gr.; the highest being 566 gr., and the lowest 346 gr. The average of the Cerebellum was 70 gr.; the highest being 76 gr., and the lowest 64 gr. The average proportion was, therefore, 1 to 5·97; the highest being 1 to 5·16, and the lowest 1 to 7·44. It is curious that this last was in the individual which had the largest Cerebellum of the whole; but the proportional weight of the Cerebrum was still greater.—Bringing together the results of these observations, they are found to be quite opposed to the statement of Gall. The weight of the Cerebrum, reckoning the Cerebellum as 1, is thus expressed in each of the foregoing descriptions of animals:—

	Average.	*Highest.*	*Lowest.*
Stallions	7·07	7·46	6·25
Mares	6·59	7·00	5·09
Geldings	5·97	7·44	5·16

proportional size of the Cerebellum in Geldings, therefore, from being *less* than that which it bears in entire Horses and it is positively greater; and this depends not only on diminu-

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[*] "Anat. Comp. du Système Nerveux," tom. i. p. 427.

tion in the relative size of the Cerebrum, but on its own larger dimension, as the following comparison of *absolute* weights will show:—

	Average.	*Highest.*	*Lowest.*
Stallions	61	65	56
Mares	61	66	53
Geldings	70	76	64

The difference is so remarkable, and appears, from examination of the individual results, to be so constant, that it cannot be attributed to any accidental circumstance arising out of the small number of animals thus examined. The average weight of the Cerebellum in the ten Stallions and twelve Mares is seen to be the same, and the extremes differ but little in the two; whilst the average in the Geldings is more than one-seventh higher, and the *lowest* is considerably above the *average* of the preceding, while the highest far exceeds the highest among the entire Horses. It is curious that Gall would have been much nearer the truth, if he had said that the dimensions of the *Cerebrum* are usually reduced by castration; for it appears from the following Table that such is really the case:—

	Average.	*Greatest.*	*Least.*
Stallions	433	485	350
Mares	402	432	336
Geldings	419	566	346

The weight of the largest Cerebrum of the Gelding is far above the highest of the Stallions; but it seems to have been an extraordinary case, as in no other was the weight above 490 gr. If this one be excluded, the *average* will be reduced still further, being then about 412; this may be seen, by looking over the whole table, to give a very fair idea of the usual weight in these animals, which is therefore *less*, by about one-twentieth, than the average in the Stallions.—The increased size of the Cerebellum in Geldings may perhaps be accounted-for, by remembering that this class of horses is solely employed for its muscular power, and that the constant exercise of the organ is not unlikely to develope its size; whilst Stallions, being kept especially for the purpose of propagation, are much less applied to occupations which call-forth their motor activity.

542. It is asserted, however, by the followers of Gall, that very strong evidence of the truth of his doctrine is afforded by Pathological phenomena: excitement of the genital organs, manifesting itself in priapism, turgescence of the testes, and seminal emissions, being an ordinary concomitant of some forms of apoplexy in which the Cerebellum is affected; whilst in other cases of disease or injury involving extensive destruction of the substance of the organ, there has been a complete abatement of sexual desire. The proportion of recorded cases of disease of the Cerebellum, however, in which any affection of the genital organs has been noticed, is extremely small; for out of 178 cases which have been collected by Burdach,* only 10, or scarcely more than 1 in 18, presented any symptoms that tended to indicate a functional relation between the Cerebellum and the Genital organs. The same physiologist affirms that similar affections present themselves when the Cerebrum is the seat of the lesion; and there seems a strong probability that it is solely to the

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* "Von Baue und Leben des Gehirns" (Leipsig, 1819–26), band iii.

connection of these organs with the Spinal Cord, that such affections of the genital apparatus are due. For erection of the penis has been noticed in a far larger proportion of cases in which the Spinal Cord itself has been the seat of the lesion; thus in 15 cases in which the cervical portion of the Cord was affected, erection of the penis was observed in 8; and in 13 cases of lesion of the dorso-lumbar portion of the Cord, erection of the penis took place in 3.[*] It is well known that erection of the penis and emissio seminis are not infrequent phenomena of death by hanging; and this fact accords fully as well with the idea that the affection of the sexual organs is consequent upon lesion of the Cranio-Spinal axis, as with the doctrine that it is due to disordered function of the Cerebellum.—It has been suggested by Serres,[†] who collected seven cases in which excitement of the genital organs was coincident with apoplexy of the median lobe of the Cerebellum, that whilst the lateral lobes or hemispheres may be connected with the locomotive function, the median lobe may be the organ of the sexual instinct. Several cases have been recorded, in which some such relation appeared to be indicated; and the Author has been made acquainted with at least six,[‡] in which an extraordinary salacity developed itself at an advanced period of life, whilst, concurrently with this, or following upon it, there was that kind of unsteadiness of gait which may be held to indicate chronic disease of the Cerebellum. In one of these cases of which the history and post-mortem appearances have been carefully recorded by Mr. Dunn,[§] there was strong evidence that the excitement of the sexual propensity was coincident with the irritative stage of incipient disease in the central lobe of the Cerebellum, and that the abatement of the propensity was in like manner coincident with the subsequent destruction of its substance; whilst the advance of the disease into the lateral lobes was marked by impairment of the power of co-ordination of movement. But with regard to all such cases, and others that may be ranked in the same category,[‖] the objection of Pétrequin[¶] holds good, that when disease or injury affects the median lobe of the Cerebellum, the Medulla Oblongata is almost certain to be implicated in it; so that, as the evidence already referred-to clearly indicates the existence of a special relation between the genital organs and the upper part of the Spinal Axis, no positive proof is afforded by them that any portion of the Cerebellum has any special connection with the generative function.

543. The Author is far from denying *in toto*, that any peculiar connection exists between the Cerebellum and the Genital system; but if the

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[*] See the "Traité des Maladies de la Moëlle Epinière" of M. Ollivier (d'Angers), 3ème édit., tom. iii. p. 316.

[†] "Anatomie Comparée du Cerveau," tom. ii. pp. 601, 717.

[‡] Four such cases came under the notice of his friend, the late Dr. Simpson, of York.

[§] "Medico-Chirurgical Transactions," vol. xxxii.

[‖] Thus, a case has been communicated to the Author by Mr. Turley, of Worcester, in which the sexual desire, which had been always strong through life, but which had been controlled within the limits of decency, manifested itself, during a period of some months preceding death, in a most extraordinary degree; on *post-mortem* examination, a tumour was found on the Pons Varolii.—And he has been informed of another case by Dr. Evanson (formerly of Dublin), in which a young officer on the eve of marriage, having received a blow on the occiput by a fall from his horse, became impotent, without any other disorder of his bodily or mental powers; and in the distress consequent upon this discovery, committed suicide on the morning fixed for his wedding.

[¶] 'Sur quelques points de la Physiologie du Cervelet et de la Moëlle Epinière,' in "Gaz. Médicale," 1836, tom. iv. p. 546.

evidence at present adduced in support of the Phrenological position be held sufficient to establish it, in defiance of so many opposing considerations, we must bid adieu to all safe reasoning in Physiology. The weight of testimony appears to him to be quite decided, in regard to the connection of the Cerebellum with the regulation of the motor function; and as an additional argument in favour of this view, it may be stated, that the lobes of the Human Cerebellum undergo their most rapid development during the first few years of life, when a large number of complex voluntary movements are being learned by experience, and are being associated by means of the muscular sensations accompanying them; whilst in those animals which have, immediately after birth, the power of regulating their voluntary movements for definite objects, with the greatest precision, the Cerebellum is more fully developed at the time of birth. In both instances it is well formed and in active operation (so far as can be judged-of by the amount of circulation through it), long before the sexual instinct manifests itself in any perceptible degree.—But neither doctrine need be maintained altogether to the exclusion of the other; and there are many among the Phrenologists of the present day, who hold, with Serres, that whilst the *hemispheres* of the Cerebellum possess the endowments now generally assigned to them by Physiologists, the *central lobe* is connected with the Genital function. It has been shown by Dr. N. S. Davis,* however, that there is no perceptible difference in the dimensions of this central lobe, any more than in those of the hemispheres, between Bulls and Oxen; and no proof has yet been offered, save that afforded by the pathological evidence just referred-to, that any such endowment is possessed by it. That in some way or other, however, either the central portion of the Cerebellum, or some part of the Medulla Oblongata, has a special connection with the Generative function, appears to the Author to be indicated with tolerable clearness by several of the Pathological phenomena already cited. The circumstance, too, of which he has frequently been assured, that great application to gymnastic exercises diminishes for a time the sexual vigour, and even totally suspends desire, seems worthy of consideration in reference to such a view; for if the Cerebellum be really connected with both kinds of function, it does not seem unreasonable that the excessive employment of it upon one should diminish its energy in regard to the other.—An analysis of the nature of the Sexual propensity, however, suggests the conclusion that we are not to look in this part of the Encephalon for anything else than a seat of the sexual *sensation;* the character of which seems to be sufficiently different from that of mere *tactile* sensation, to require a distinct ganglionic centre. Such a centre would be likely to be placed in the line of the other sensory ganglia, and in close connection with them.

544. As in the case of other sensations, the Sexual, when moderately excited, may give rise to ideas, emotions, and desires, of which the Cerebrum is the seat; and these may react on the muscular system through the Intelligence and Will. But when inordinately excited, or when not kept in restraint by the Will, the sexual sensations will at once call into play respondent movements, which are then to be regarded as purely automatic; this is the case in Nymphomania and Satyriasis in the Human

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* "Transactions of American Medical Association," vol. iii. p. 415.

subject; and it is probably also the ordinary mode of operation of this sense, in such of the lower animals as have not psychical power enough to form a conception of an absent object of gratification, and cannot, therefore, be said to have sexual *desires*. Thus, like other sensations, it may act either *intelligentially* or *automatically*; giving rise to *ideas*, by transmission to the Cerebrum, which ideas, associated with pleasurable feelings, originate *desires* that stimulate the Reasoning powers to devise means for their gratification, and excite the Will to the necessary actions; or, by its immediate action upon the motor apparatus, producing respondent *movements*.—Of this double *modus operandi* we seem to have sufficient evidence. For among many of the lower tribes of animals, at the time when the generative organs are in a state of functional activity, the presence of an individual of the opposite sex, indicated by the sight, smell, hearing, or touch, immediately excites the whole train of instinctive actions concerned in the reproductive operation; whilst we have no evidence in them of any voluntary exertion, resulting from the existence of a desire entertained in the absence of the object, and intended for the gratification of that desire. In Man, on the other hand, the principal operation of the sexual sensations is in awakening desires and affections, which serve as excitements to the intelligence and as motives to the Will; and it is only, under ordinary circumstances, when the two sexes have been thus brought into close relation, that the direct reaction of the sexual sensation manifests itself in automatic movements. In cases, however, in which this sensation is excited in unusual strength, it may completely overmaster all motives to the repression of the propensity, and may even entirely remove the actions from volitional control; and a state of a very similar kind exists in many Idiots, in whom the sexual propensity exerts a dominant power, not because it is in itself peculiarly strong, but because, the Intelligence being undeveloped, it acts without restraint or direction from the Will.

5. *The Cerebrum, and its Functions.*

545. We come, in the last place, to consider the functions of that portion of the Nervous Centres, which is evidently, in Man, the predominant organ of his whole system; being not merely the instrument of his Reasoning faculties, but also possessing a direct or indirect control over nearly all the actions of his corporeal frame, save those purely vegetative processes which are most completely isolated from his animal powers. We should be in great danger, however, of coming to an erroneous conclusion as to the real character of the Cerebrum and of its operations, if we confined ourselves to the study of the Human organism; and the history of Physiological science shows that every advance of knowledge respecting its functions has tended to *limit* them, whilst at the same time rendering them *more precise*. Thus the Brain (this term, in the older Anatomy, being chiefly appropriated to the Cerebrum) was once accounted not merely the centre of all motion and sensation, but also the source of all vitality; the different processes of nutrition, secretion, &c., being maintained, it was supposed, by a constant supply of 'animal spirits,' propagated from the brain, along the nerves, to each individual part. The more modern doctrine, that the Sympathetic System has for its special function

to supply the nervous influence requisite for the maintenance of the functions of Organic life, was the first step in the process of limitation; still the Brain was regarded as the centre of all the Animal functions; and no other part was admitted to possess any power independently of it. By experiments and pathological observations, however, the powers of the Spinal Cord as an independent centre of action were next established; and it was thus shown that there is a large class of motions in which the Brain has no concern, and that the removal of the Cerebral hemispheres is not incompatible (even among the higher Vertebrata) with the prolonged maintenance of a sort of inert and scarcely conscious life. Still, it has been usually maintained, and with great show of reason, that the Cerebrum is the instrument of all *psychical* operations, and the originator of *all* the movements which could not be assigned to the reflex action of the Spinal Cord. An attempt has been made, however, in the preceding pages, to show that this view is not correct; and that there is a class of actions, neither excito-motor nor voluntary, but directly consequent upon Sensations, and constituting (with the excito-motor) the truly *instinctive* actions, which may be justly assigned to certain ganglionic centres not less independent of the Cerebrum than is the Spinal Cord itself. It has been further pointed-out that the Cerebrum must be considered in the light of an organ *superadded* for a particular purpose or set of purposes, and not as one which is essential to life; that it has no representative among the Invertebrata (except in a few of the highest forms, which evidently present a transition towards the Vertebrated series); and that, at its first introduction in the class of Fishes, it evidently performs a subordinate part in the general actions of the Nervous System. Hence, whatever be the function, or set of functions, we assign to the Cerebrum, we must keep in view the *special* character of the organ; and must never lose sight of the fact, that its predominance in Man does not deprive other parts of their independent powers, although it may keep the exercise of those powers in check, and may considerably modify their manifestations.

546. Before proceeding to inquire into the Physiology of the Cerebrum, we may advantageously take notice of some of the leading features of its structure.*—In the first place, it forms an exception to the general plan on which the elements of ganglionic centres are arranged; in having its vesicular substance on the *exterior*, instead of in the *central* part of the mass. The purpose of this is probably to allow the vesicular matter to be disposed in such a manner as to present a very large *surface*, instead of being aggregated-together in a more compact mass; and by this means to admit, on the one side, a more ready access of the blood-vessels which are so essential to the functional operations of this tissue, as well as a more ready communication, on the other, with the vast number of fibres by which its influence is to be propagated. There is no reason whatever to believe, that the relative functions of the vesicular and fibrous substances are in the least altered by this change in their relative position; indeed, the results of observation upon the phenomena of disordered Cerebral action are such as to afford decided confirmation to the doctrine now generally accepted, that the action of the Vesicular matter constitutes the *source* of nervous power, whilst the Fibrous structure has for its

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* For further details of the minute anatomy of the Cerebral substance, see Lockhart Clarke in the "Proceedings of the Royal Society," vol. xii. No. 57.

office to *conduct* the influence thus generated to the points at which it is to operate. The purpose of this arrangement is further evidenced by the fact, that, in all the higher forms of Cerebral structure, we find a provision for a still greater extension of the surface at which the vesicular matter and the blood-vessels may come into relation; this being effected by the plication of the layer of vesicular matter into 'convolutions,' into the sulci between which the highly vascular membrane known as the 'pia-mater' dips down, sending multitudes of small vessels from its inner surface into the substance it invests.

547. The *Cortical* substance or 'grey matter' of the Hemispheres essentially consists of that *vesicular* nerve-substance, which, in the Spinal Cord, as in ganglionic masses generally, is found to occupy the interior. Its usual thickness is about one-fifth of an inch; but considerable variations present themselves in this respect, as also in the depth of the convolutions. Thus the plications are deepest, and the layer of 'grey matter' the thickest, during the period of greatest nervous energy, that is, in middle life; in infancy and in old age, the convolutions are simpler and have fewer undulations, and the thickness of their cortical substance is much inferior; and the same is true of the adult brain of some of the least cultivated races of mankind. Three layers of somewhat different hues may be distinguished in the cortical substance; the external, *white;* the middle, *pure grey;* the internal, *yellowish red.* The external one, however, may generally be subdivided into two, and the internal one into four; namely, two white laminæ, alternating with two yellowish-red laminæ. Throughout its entire thickness, nerve-cells and nerve-fibres are intermixed; and these are imbedded in a granular matrix-substance. The nerve-cells are for the most part remarkable for the number of pale slender branching processes which they give-off; and these have been unequivocally proved by observation to be continuous with some (at least) of the fibres which are found in close relation to them. These cells are most abundant in the middle or pure-grey layer, and next to this in the internal or yellowish-red layer; on the other hand, in the external white layer, and in the white streaks of the internal layer, the fibres spread-out in a plane that is nearly parallel to the surface. The further the fibres penetrate from the medullary stratum into the cortical substance, the finer do they become; and in the external white lamina, in which they form numerous superimposed layers, and cross each other in various directions, they are reduced to the very smallest dimensions. It seems certain that both in this and also in the grey layer, *some* of the fibres return by loops; although it has not been yet found possible to determine to what order of fibres these belong.*

548. In the *Medullary* or *fibrous* substance, of which the great mass of the Cerebrum is composed, three principal sets of fibres may be distinguished. These are,—*first*, the radiating fibres, which connect the vesicular matter of the cortical substance of the Hemispheres with the Thalami Optici, and which, if our view of the function of the latter be correct, may be regarded as *ascending;*—*second*, the radiating fibres which connect the vesicular matter of the cortical substance of the

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* See Prof. Kölliker's "Manual of Human Histology" (Syden. Soc.), vol. i. pp. 439–443; his "Mikroskopische Anatomie," band ii. § 119; and his "Manual of Microscop. Anatomy."

Hemispheres with the Corpora Striata, and which, on similar grounds, may be regarded as *descending;*—and *third,* the Commissural fibres, which establish the connection between the opposite Hemispheres, and between the different parts of the vesicular substance of the same side, especially between that disposed on the surface of each hemisphere and those isolated patches which are found in its interior. It is on the very large proportion which the Commissural fibres bear to the rest, that the bulk of the Cerebrum of Man and of the higher animals seems chiefly to depend; and it is easy to conceive that this condition has an important relation with the operations of the Mind, whatever be our view of the relative functions of different parts of the Cerebrum. It appears from the late researches of M. Baillarger, that the *surface* and the *bulk* of the cerebral hemispheres are so far from bearing any constant proportion to each other, in different animals, that, notwithstanding the depth of the convolutions in the Human Cerebrum, its bulk is 2½ times as great in proportion to its surface, as it is in the Rabbit, the surface of whose Cerebrum is smooth. The entire surface of the Human Cerebrum is estimated by him at about 670 square inches.*

Fig. 121.

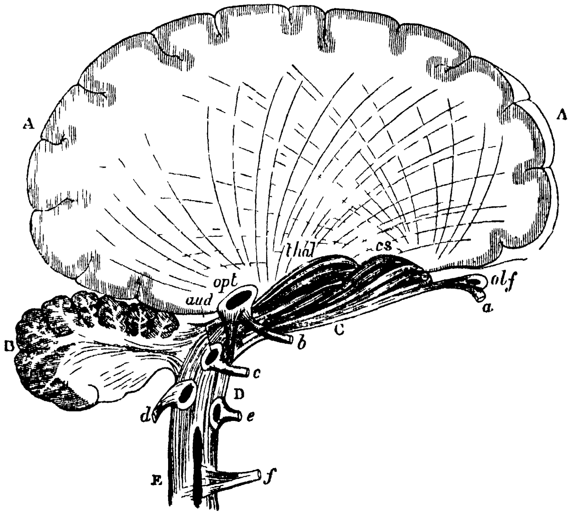

Diagram of the mutual relations of the principal Encephalic centres, as shown in a vertical section —A, Cerebrum; B, Cerebellum; C, Sensori-motor tract, including the Olfactive ganglion *olf,* the Optic *opt,* and the Auditory *aud,* with the Thalami Optici *thal,* and the Corpora Striata *cs,* D, Medulla Oblongata, E, Spinal Cord,—*a,* olfactive nerve, *b,* optic; *c,* auditory; *d,* pneumogastric, *e,* hypoglossal, *f,* spinal fibres of the medullary substance of the Cerebrum are shown, connecting its ganglionic surface with the Sensori-motor tract.

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* The inference drawn by M. Baillarger from the facts he has collected,—namely, that the proportional surface of vesicular matter in different animals, whether considered absolutely, or relatively to the volume of the Cerebrum, has no correspondence with their intellectual capability,—is far too sweeping an assumption; since, as above shown, the increase in the commissural fibres, causing an augmentation of the bulk of the Cerebrum, may be alike the cause of increased intelligence and of a diminished proportional amount of vesicular matter, though the latter still remains as the original source of power.

549. With regard to the *Radiating* fibres, which connect the Corpora Striata and Thalami Optici with the vesicular surface of the Cerebral hemispheres, not only has no positive proof yet been obtained of their direct *continuity* with those which enter into the composition of the nerves proceeding from the Spinal Cord and Medulla Oblongata; but the results of the most recent and careful examination are in opposition to such an idea (§ 502). And we have seen that there are certain phenomena, which are best explained by considering these radiating fibres as of a *commissural* nature only; and as serving to connect the vesicular matter of the Cerebrum with that of the higher portions of the *Cranio-Spinal Axis*, through which alone they are brought into relation with the central terminations of the afferent nerves, and with the origins of the motor (§ 527).—Thus the Anatomical relation which the grey matter of the Cerebral convolutions bears to the central Sensorium, precisely corresponds with that which is borne to it by the Retina, which essentially consists, like it, of an expansion of vesicular substance; whilst the radiating fibres of the medullary substance answer precisely to the Optic Nerve. And it is a most important confirmation of this view, that such a relation is also shown to exist by the history of Development. For the cortical substance of the Cerebrum and the Retina alike originate as offsets from the Sensory Ganglia; the former detaching itself from the Corpus Striatum on either side, the latter from the Thalamus Opticus; and each being gradually removed to a greater and greater distance from its original centre, by the elongation of the intervening commissural tract. It seems to have been a kind of recognition of this analogy, which long since led the sagacious Reil to designate the Cerebral lobes as a congeries of 'nerves of the internal senses.'*

550. The *Commissural* fibres constitute two principal groups, the *transverse* and the *longitudinal;* the former connecting the two Hemispheres with each other; the latter uniting the different parts of the same Hemisphere.—Of the transverse commissures, the *Corpus Callosum* is the most important. This consists of a mass of fibres very closely interlaced together; which may be traced into the substance of the hemispheres on each side, particularly at their lower part, where their connections are the closest with the Thalami Optici and Corpora Striata. It is difficult, if not impossible, to trace its fibres any further; but there can be little doubt that they radiate, with the fibres proceeding from the bodies just named, to different parts of the cortical substance of the Hemispheres. This commissure is altogether wanting in Fish, Reptiles, and Birds; and it is partially or completely wanting in those Mammals whose Cerebrum is formed upon the least complex plan,—the Rodents and Marsupials. Although the *Anterior* commissure particularly unites the Corpora Striata of the two sides, many of its fibres pass through those organs, and radiate towards the convolutions of the Hemispheres, especially those of the middle lobe: this commissure is particularly large in those

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* He says, "The nerves of the external senses and voluntary muscles escape from the cranium forwards and backwards, and ramify over the whole of the body so as to connect it with the organ of the soul; the nerves of the internal senses [moral and intellectual faculties], on the other hand, have no object beyond the cranium, and are therefore found rolled-up on themselves and forming the masses of the brain." ("Archiv fur Physiol.," 1802, band vi. s. 406.)

Marsupials in which the Corpus Callosum is deficient.—Of the *longitudinal* commissures, some lie above and others below the Corpus Callosum. Upon the transverse fibres of that body there is a longitudinal tract on each side of the median line, which serves to connect the convolutions of the anterior and posterior Cerebral lobes. Above this, again, is the *Superior longitudinal* commissure, which is formed by the fibrous matter of the greater convolutions nearest the median plane on the upper surface of the Cerebrum, and which connects the convolutions of the anterior and middle lobes with those of the posterior. Beneath the Corpus Callosum, we find the most extensive of all the longitudinal commissures, the *Fornix.* This is connected in front with the Thalami Optici, the Corpora Mammillaria, the Tuber Cinereum, &c.; and behind, it spreads its fibres over the Hippocampi (major and minor), which are nothing else than peculiar convolutions that project into the posterior and descending cornua of the lateral ventricles. The fourth longitudinal commissure is the *Tœnia semicircularis*, which forms part of the same system of fibres with the fornix; connecting the corpus mammillare and thalamus opticus of each side with the middle lobe of the cerebral hemisphere. If, as Dr. Todd has remarked,* we could take away the corpus callosum, the grey matter of the internal convolution, and the ventricular prominence of the optic thalami, then all these commissures would fall-together, and would become united in the same series of longitudinal fibres.—Experiment does not throw any light upon the particular functions of the Corpus Callosum and other Commissures; since they can scarcely be divided without severe general injury. It would appear, however, that the partial or entire absence of these parts, reducing the Cerebrum (in this respect at least) to the level of that of the Marsupial Quadruped or of the Bird, is by no means an unfrequent cause of deficient intellectual power.†

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* "Anatomy of the Brain, Spinal Cord," &c., p. 234.

† The following case of deficient commissures, recorded by Mr. Paget ("Medico-Chirurg. Transactions," vol. xxiv.), is of much interest. The middle portion of the Fornix, and the whole of the Septum Lucidum, were absent; and in place of the Corpus Callosum, there was only a thin fasciculated layer of fibrous matter, 1·4 inch in length, of which, however, the fibres extended to all the parts of the brain into which the fibres of the healthy corpus callosum can be traced. The Middle commissure was very large; and the lateral part of the Fornix, with the rest of the Brain, was quite healthy. The patient was a servant-girl, who died of pericarditis. She had displayed nothing very remarkable in her mental condition, during her life, beyond a peculiar *want of forethought* and *power of judging of the probable event of things.* Her memory was good; and she possessed as much ordinary knowledge as is commonly acquired by persons in her rank of life. She was of good moral character, trustworthy, and fully competent to all the duties of her station, though somewhat heedless; her temper was good, and disposition cheerful.—The mental deficiencies in most of the few other cases of which the details have been recorded, seem to have been of the same order; and this is exactly what might have been anticipated; since the deprivation of these parts takes away that which is most characteristic of the Cerebrum of Man and of the higher Mammalia; *their* intellectual operations being peculiarly distinguished by that *application of past experience to the prediction of the future,* which constitutes one of the highest efforts of intelligence.—Another case has been since put on record by Mr. Mitchell Henry (Op. cit., vol. xxxi.), in which the anterior portion of the Corpus Callosum was deficient, together with the middle and anterior portion of the Fornix, and the whole of the Septum Lucidum. There was in this case, also, a marked intellectual deficiency, but apparently of a different character from that which showed itself in the preceding case; for instead of vivacity and habitual rapidity of action, there was here a disproportionate degree of slowness in action, amounting almost to stupidity. The difference in the two cases, however, is perhaps to be set-down rather to the account

551. The weight of the entire Encephalon in the adult Male usually ranges between 40 and 60 oz., the average being about 50 oz.; and in the Female from 36 to 50 oz., the average being about 45 oz. The maximum of the healthy brain seems to be about 64 oz., and the minimum about 31 oz. But in cases of Idiocy, the amount is sometimes much below this; as low a weight as 20 oz. having been recorded.—It appears, from the investigations of M. Bourgery, that the relative sizes of the different component elements of the Human Encephalon are somewhat as follows. Dividing the whole into 204 parts, the weight of the Cerebrum will be represented by about 170 of those parts, that of the Cerebellum by 21, and that of the Medulla Oblongata with the Optic Thalami and Corpora Striata at 13. The weight of the Spinal Cord would be, on the same scale, 7 parts. Hence the Cerebral Hemispheres of Man include an amount of nervous matter, which is *four* times that of all the rest of the Cranio-Spinal mass, more than *eight* times that of the Cerebellum, *thirteen* times that of the Medulla Oblongata, &c., and *twenty-four* times that of the Spinal Cord.—The average weight of the whole Encephalon in proportion to that of the body, in Man, taking the average of a great number of observations, is about 1 to 36. This is a much larger proportion than that which obtains in most other animals; thus the average of Mammalia is stated by M. Leuret to be 1 to 186, that of Birds 1 to 212, that of Reptiles 1 to 1321, and that of Fishes 1 to 5668. It is interesting to remark, in reference to these estimates, that the Encephalic prolongation of the Medulla Oblongata in Man (being about one-sixteenth of the weight of the whole Encephalon) is *alone* more than twice as heavy in proportion to his body, as the *entire* Encephalon of Reptiles, and ten times as heavy as that of Fish.—But there are some animals in which the weight of the Encephalon bears a higher proportion to that of the body than it does in Man; thus in the Blue-headed Tit, the proportion is as 1 to 12, in the Goldfinch as 1 to 24, and in the Field-Mouse as 1 to 31. It does not hence follow, however, that the *Cerebrum* is larger in proportion; in fact, it is probably not nearly so large; for in Birds and Rodent Mammals, the Sensory Ganglia form a very considerable proportion of the entire Encephalon. The importance of distinguishing between the several parts of this mass, which are marked-out as distinct alike by their structure and connections and by the history of their development, has not been by any means sufficiently attended to.

552. The Encephalon altogether receives a supply of Blood, the amount of which is very remarkable, when its comparative bulk is considered; the proportion which goes to it being, according to the estimate of Haller, as much as one-fifth of the whole mass. The manner in which this blood is conveyed to the brain, and the conditions of its distribution, offer some peculiarities worthy of notice. The two Vertebral and two Carotid arteries, by which the blood enters the cavity of the cranium, have a more free communication by anastomosis than any similar set of arteries elsewhere; and this is obviously destined to prevent an obstruction in one trunk from interrupting the supply of blood to the parts through which its branches are chiefly distributed,—the cessation of the circulation through the nervous matter being immediately productive of

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of general temperament; since in both of them there seems to have been a deficiency in the power of carrying-on a continuous train of thought.

suspension of its functional activity.*—Not only must there be a sufficient supply of blood, but it must make a regulated pressure on the walls of the vessels. Now the Encephalon is differently circumstanced from other vascular organs, in being enclosed within an unyielding bony case (§ 254); and we find a special provision for equalizing the bulk of the contents of this cavity, and for counterbalancing the results of differences in the functional activity of the brain and in its supply of blood, in the existence of a fluid which is found beneath the arachnoid, both on the surface of the brain and spinal cord, and in the ventricles of the former. The amount of this 'cerebro-spinal fluid' seems to average about two ounces; but in cases of atrophy of the brain, as much as twelve ounces of fluid may sometimes be obtained from the cranio-spinal cavity; whilst in all instances in which the bulk of the brain has undergone an increase, whether from the production of additional nervous tissue, or from undue turgescence of the vessels, there is either a diminution or a total absence of this fluid. It appears from the experiments of Magendie (to whom our knowledge of its importance is chiefly due), that its withdrawal in living animals causes great disturbance of the cerebral functions, probably by allowing undue distension of the blood-vessels; it is, however, capable of being very rapidly regenerated; and its reproduction restores the nervous centres to their natural state.—As the 'cerebro-spinal fluid' can readily find its way from the sub-arachnoid spaces of the *cranial* cavity into those of the *spinal*, and as it is no less readily absorbed than reproduced, it evidently serves as an equalizer of the amount of pressure within the cranial cavity; admitting the distension or contraction of the vessels to take place, within certain limits, without any considerable change in the degree of compression to which the nervous matter is subjected. That this uniformity is of the greatest importance to the functional exercise of the brain, is evident from a few well-known facts. If an aperture be made in the skull, and the protruding portion of the brain be subjected to pressure, the immediate suspension of the activity of the whole organ is the result; in this manner, a state resembling profound sleep can be induced in a moment, the normal activity being renewed *as* momentarily so soon as the pressure is withdrawn.† This phenomenon has often been observed in the Human subject, in cases in which a portion of the cranial envelope has been lost by disease or injury. The various symptoms of Cerebral disturbance which are due to a state of general Plethora, are evidently owing to an *excess* of pressure within the vessels; but an undue *diminution* of pressure is no less injurious, as appears from the disturbance in the Cerebral functions which results from the very opposite cause, namely a depression of the power of the heart, or a deficiency of blood in the vessels.—It is of peculiar importance to bear in mind the disturbance of the Cerebral functions occasioned by variations of internal *pressure*, when we are endeavouring to draw inferences from the phenomena presented by disease.

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* M. Robin ("Journal de la Physiologie," vol. ii. p. 537) has described an accessory tissue around the capillaries of the brain, in the space between which and the proper Tunica adventitia, free nuclei, fatty masses, and granules of hæmatosine, are observable. M. Robin seems to be of opinion that these are the lymphatics of the brain.

† Schiff states that the Indian snake-charmers are accustomed to produce rigidity of the body by pressure on the occiput.

553. We shall now proceed with our Physiological inquiry into the functions of the Cerebrum; and shall appeal, as before, to Human and Comparative Anatomy, to Experiment, and to Pathology, for our chief data.—The anatomical relations of the Cerebrum to the other Encephalic centres, clearly demonstrate that it is not one of the essential or fundamental portions of the Nervous system; but a superadded organ, receiving all its impulses to action from the parts below, and operating upon the body at large through them. And its great bulk, joined to its position at the summit of the whole apparatus,—the vesicular substance of its convolutions affording a termination to the fibres in connection with it, and not being for the most part only traversed by them, as is the case with that of all the lower centres,—clearly mark it out as the highest in its functional relations, and as ministering, so far as any material instrument may do, to the exercise of those psychical powers, which, in Man, exhibit so remarkable a predominance over the mere animal instincts. This conclusion is fully borne-out, when we extend our inquiries from Human to Comparative Anatomy; for with some apparent exceptions, which there would probably be no great difficulty in explaining if we were in possession of all the requisite data, there is a very close correspondence between the relative development of the *Cerebrum* in the several tribes of Vertebrata,* and the degree of *Intelligence* they respectively possess,—using the latter term as a comprehensive expression of that series of mental actions, which consists in the *intentional* adaptation of means to ends, based on definite *ideas* as to the nature of both. It is not always easy to say, in the case of the lower animals, what parts of their actions are to be attributed to automatic impulses (*i.e.* to be considered as Instinctive), and what should be regarded as the results of Intelligence. The character of Intelligent actions, however, as compared with Instinctive (§ 430), is usually shown (1) in the *variety* of means which are adopted to compass the same ends, and this not merely by different individuals and by successive generations, but by the same individual at different times; (2) by the improvement in the mode of accomplishing the object, which results from the intelligent use of experience, and from the greater command of means which is progressively attained; and (3) by the conformity of the means to altered circumstances, so that the character of adaptiveness is still maintained, however widely the new conditions may depart from those which must be considered as natural to the species.

554. The difference between actions which proceed from the Intellectual faculties prompted by the instinctive propensities, and those of a purely Instinctive character, is well seen in comparing Birds with Insects. The Instinctive tendencies of the two classes are of nearly the same kind; and the usual arts which both exhibit in the construction of their habitations, in procuring their food, and in escaping from danger, must be regarded as intuitive, on account of the uniformity with which they are practised by different individuals of the same species, and the perfection with which they are exercised on the very first occasion. But in the adaptation of their operations to peculiar circumstances, Birds display a variety and fertility of resource, far surpassing that which is manifested by Insects; and it can scarcely be doubted by those who attentively

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* See "Princ. of Comp. Phys.," § 662 *et seq.*

observe their habits, that in such adaptations they are often guided by real Intelligence. This must be the case, for example, when they make trial of several means, and select that one which best answers the purpose; or when they make an obvious improvement from year to year in the comforts of their dwelling; or when they are influenced in the choice of a situation by peculiar circumstances, which in a state of nature can scarcely be supposed to affect them. The complete domesticability of many Birds is in itself a proof of their possessing a certain degree of intelligence; but this alone does not indicate the possession of more than a very low amount of it; since many of the most domesticable animals are of the humblest intellectual capacity, and seem to become attached to Man, principally as the source on which they depend for the supply of their animal wants. But there are certain tribes of Birds, especially the Parrots and their allies, which possess an extraordinary degree of *educability*, and which manifest a power of performing simple acts of *reasoning*, that are quite comparable with those of a child when first learning to talk.

555. This development of the Intelligence under the influence of Man, and in accordance with *his* habits rather than with the original habits of their species, is yet more remarkable in the case of those Mammals whose instincts lead them to attach themselves peculiarly to him, and whose powers of reasoning are called-forth in adapting themselves to the new circumstances in which they are thus placed. The actions of a Dog, a Horse, or an Elephant are evidently the result, in many instances, of a complex train of reasoning, differing in no essential respect from that which Man would perform in similar circumstances; so that the epithet 'half-reasoning,' commonly applied to these animals, does not express the whole truth; for their mental processes are of the same *kind* with those of Man, and differ more in the *degree* of comprehensiveness of their data and conclusiveness of their inferences, than they do in their essential character. We have no evidence, however, that any of the lower animals have a voluntary power of *directing* their mental operations, at all similar to that which Man possesses; these operations, indeed, seem to be of very much the same character as those which we perform in connected dreams, different trains of thought commencing as they are suggested, and proceeding according to the usual laws, until some other disturb them.—Although it is customary to regard the Dog and the Elephant as the most intelligent among the lower animals, it is not certain that we do so with justice; for it is very possible that we are misled by that peculiar attachment to Man, which in them must be termed an instinct, and which enters as a motive into a large proportion of their actions; and that, if we were more acquainted with the psychical characters of the higher Quadrumana, we should find in *them* a greater degree of mental capability than we now attribute to them. One thing is certain, that the higher the degree of Intelligence which we find characteristic of a particular race, the greater is the degree of variation which we meet-with in the characters of individuals; thus everybody knows that there are stupid Dogs and clever Dogs, ill-tempered Dogs and good-tempered Dogs,—as there are stupid Men and clever Men, ill-tempered Men and good-tempered Men. But no one could distinguish between a stupid Bee and a clever Bee, or between a good-tempered Wasp and an ill-tempered Wasp, simply because all *their* actions are prompted by an unvarying Instinct.

556. In estimating the relative development of the Cerebrum in different tribes of Animals, and in comparing this with their relative Intelligence, it must be borne in mind that the *size* of the organ does not, considered alone, afford a means of accurate judgment as to its *power*. For the quantity of vesicular matter which it contains, affords the only fair criterion of the latter; and of this we must judge, not merely by the superficial area, but by the number and depth of the convolutions, and by the thickness of the cortical layer. Again, there are many reasons why it is not fair to estimate the relative development of the Cerebrum by the proportion which it bears to the whole bulk of the animal; and, on the whole, the most accurate basis of comparison would probably be afforded by the relation between the bulk of the Cerebrum and the diameter of the Spinal Cord. In making any such comparison, however, the Thalami Optici, Corpora Striata, and Corpora Quadrigemina should be excluded from the estimate, for reasons now sufficiently apparent; and the bulk of the Cerebrum *proper* should be alone determined, either by weight, or by the displacement of liquid.—But the Cerebrum varies in different classes and orders of Vertebrata, not merely in proportional size, but also in the relative development of its anterior, middle, and posterior lobes. This is a point of very great importance, in determining the value to be assigned to the organological system of Gall and Spurzheim and their followers. The Cerebrum of the Oviparous Vertebrata is *not* a miniature representative of that of Man, as a whole, but only of his *anterior* lobes; as is sufficiently obvious from an examination of its connections with other parts, and from the absence of any other commissural connections between its two hemispheres than those which are afforded by the Sensory Ganglia. It is in the Implacental Mammals that we find the first rudiment of the *middle* lobes of the Cerebrum, and of the proper inter-cerebral commissure, the Corpus Callosum; and even in the Rodents this is but very imperfectly developed. As we ascend the Mammalian series, we find the Cerebrum becoming more and more elongated posteriorly by the development of the middle lobes, and the inter-cerebral commissure becomes more complete; but we must ascend as high as the Carnivora, before we find the least vestige of the *posterior* lobes; and the rudiment which these possess is so rapidly enlarged in the Quadrumana, that in some of that group the posterior lobes are as fully developed in reference to the Cerebrum as a whole, and as completely cover in the Cerebellum, as in the Human subject.*—The attention which has yet been given to this department of inquiry, has not hitherto done more than confirm the statement already made, with regard to the

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* It has been asserted by the followers of Gall, that the development of the Cerebrum from behind forwards, as above described, is rather apparent than real: the whole organ being in fact pushed backwards by the excessive development of the anterior lobe. But the anatomical distinction between the anterior and middle lobes is sufficiently obvious externally; and that of the middle and posterior lobes is also clearly marked-out by the development of the posterior cornua of the lateral ventricles, and the situation of the hippocampus major. Hence the facts above stated do not admit of any such interpretation; and they are fully borne-out by the history of the Embryonic development of the Cerebrum in Man, which precisely follows the above plan —It is not here denied that the anterior lobe of the Human Cerebrum is remarkable for its great extension *forwards*: but still, the difference between the Cerebrum of Man and that of the lower Mammalia consists much rather in the proportional development of the posterior lobes, than in that of the anterior.

general correspondence between the development of the Cerebrum and the manifestations of Intelligence; very decided evidence of which is furnished by the great enlargement of the Cerebrum, and the corresponding alteration in the form of the Cranium, which present themselves in those races of Dogs most distinguished for their educability, when compared with those whose condition approximates most closely to what was probably their original state of wildness.

557. This general inference drawn from Comparative Anatomy, is borne-out by observation of the Human species. When the Cerebrum is fully developed, it offers innumerable diversities of form and size among various individuals; and there are as many diversities of character. It may be doubted if two individuals were ever exactly alike in this respect. That a Cerebrum which is greatly under the average size is incapable of performing its proper functions, and that the possessor of it must necessarily be more or less idiotic, there can be no reasonable doubt. On the other hand, that a large well-developed Cerebrum is found to exist in persons who have made themselves conspicuous in the world in virtue of their intellectual achievements, may be stated as a proposition of equal generality. In these opposite cases, we witness most distinctly the antagonism between the Instinctive and Voluntary powers. Those unfortunate beings in whom the Cerebrum is but little developed, are guided almost solely by their instinctive tendencies, which frequently manifest themselves with a degree of strength that would not have been supposed to exist; and occasionally new instincts present themselves, of which the Human being is ordinarily regarded as destitute.* On the other hand, those who have obtained most influence over the *understandings* of others, have always been large-brained persons, of strong intellectual and volitional powers, whose emotional tendencies have been subordinated to the reason and will, and who have devoted their whole energy to the particular objects of their pursuit.—It is very different, however, with those who are actuated by what is ordinarily termed *genius;* and whose influence is rather upon the *feelings* and *intuitions*, than upon the understandings, of others. Such persons are often very deficient in the power of even comprehending the ordinary affairs of life; and still more commonly they show an extreme want of judgment in the management of them, being under the immediate influence of their passions and emotions, which they do not sufficiently endeavour to control by their intelligent will. The life of a 'genius,' whether his bent be towards poetry, music, painting, or pursuits of a more material character, is seldom one which can be held-up for imitation. In such persons, the *general* power of the mind being low, the Cerebrum is not usually found of any great size.—The *mere* comparative size of the Cerebrum, however, affords no accurate measure of the amount of mental power; for we not unfrequently meet with men possessing large and well-formed heads, whose psychical capability is not greater than that of others, the dimensions of whose crania have the same general proportion, but are of

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* A remarkable instance of this was published some years since:—A perfectly idiotic girl, in Paris, having been seduced by some miscreant, was delivered of a child without assistance; and it was found that she had *gnawed* the umbilical cord in two, in the same manner as is practised by the lower animals. It is scarcely to be supposed that she had any idea of the *object* of this separation.

much less absolute size. Large brains, with deficient activity, are commonly found in persons of what has been termed the *phlegmatic* temperament, in whom the general processes of life seem in a torpid and indolent state; whilst small brains and great activity betoken what are known as the *sanguine* and *nervous* temperaments.

558. Having now inquired into the evidence of the *general* functions of the Cerebrum, which may be derived from examination of its Comparative development, we proceed to our other sources of information, Experiment and Pathological phenomena. From neither of these, however, is much positive information to be derived.—All the results of experiments concur to establish the fact, that no irritation, either of the vesicular or of the fibrous substance, produces either sensation or motion. These results are borne-out by pathological observations in Man; for it has been frequently remarked, when it has been necessary to separate protruded portions of the Brain from the remainder, that this has given rise to no sensation, even in cases in which the mind has been perfectly clear at the time, nor has any convulsive action been produced. The results of partial mutilations are usually, in the first instance, a general disturbance of the Cerebral functions; which subsequently, however, more or less quickly subsides, leaving but little apparent affection of the animal functions, except muscular weakness. The whole of *one* Hemisphere has been removed in this way, without any evident consequence, save a temporary feebleness of the limbs on the opposite side of the body, and what was supposed to be a deficiency of sight through the opposite eye. The former was speedily recovered-from, and the animal performed all its movements as well as before; the latter, however, was permanent, but the pupil remained active. When the upper part only of both Cerebral Hemispheres was removed by Hertwig, the animal was reduced, for fifteen days, to nearly the same condition with the one from which they had been altogether withdrawn; but afterwards sensibility evidently returned, and the muscular power did not appear to be much diminished.—The effects of the entire removal of the Cerebral Hemispheres have been already stated (§ 512). So far as any inferences can be safely drawn from them, these fully bear-out the conclusion that the Cerebrum is the organ of Intelligence; since the animals which have suffered this mutilation appear to be constantly plunged in a profound sleep, from which no irritation ever seems able to arouse them into full activity, although they give manifestations of consciousness. It would be wrong hence to infer, however, as some have done, that such would be the natural condition of an animal without a Cerebrum; since it is obvious that much of the disturbance of the sensorial powers which is occasioned by this operation, is fairly attributable to the laying-open of the cranial cavity, to the disturbance of the normal vascular pressure, and to the injury necessarily done to the parts which are left, by their severance from the Cerebrum. Hence the persistence of consciousness, after the entire removal of the Cerebrum,—which proves that the Cerebrum is *not* its seat, or at least *not its exclusive* seat,—is a far more important fact than the positive destruction of psychical power which is consequent upon the operation. So far as they can be trusted, however, the results of such mutilations bear-out the views already put-forth, as to the superadded and non-essential character of the Cerebrum; and justify

us in applying to the higher animals the inferences to which we should be led by the contemplation of those forms of the nervous system in which no Cerebrum exists. There is nothing, therefore, to oppose the conclusion, that whilst *sensations* may be felt, and sensori-motor actions excited, independently of the Cerebrum,* the presence of this organ is essential to the formation of *ideas* or notions respecting the objects of sense, and to the performance of those psychical operations for which ideas furnish at once the material and the stimulus to activity.

559. The information afforded by Pathological phenomena is equally far from being definite. Many instances are on record in which extensive disease has occurred in *one* Hemisphere, so as almost entirely to destroy it, without either any obvious injury to the mental powers, or any interruption of the influence of the mind upon the body. But there is no case on record of any such severe lesion of *both* hemispheres, in which morbid phenomena were not evident during life. It is true that, in Chronic Hydrocephalus, a very remarkable alteration in the condition of the Brain sometimes presents itself, which might *à priori* have been supposed destructive to its power of activity; the ventricles being so enormously distended with fluid, that the cerebral matter has seemed like a thin lamina spread over the interior of the enlarged cranium. But there is no proof that absolute destruction of any part was thus occasioned; and it would seem that the very gradual nature of the change gives to the structure time for accommodating itself to it. This, in fact, is to be noticed in all diseases of the Encephalon. A *sudden* lesion, that may be so trifling as to escape observation unless this be very carefully conducted, will occasion very severe symptoms; whilst a chronic disease may gradually extend itself, without any external manifestation. It will usually be found that sudden paralysis, of which the seat is in the Brain, results from some slight effusion of blood in the substance or in the neighbourhood of the Corpora Striata; whilst, if it follow disorder of long standing, a much greater amount of lesion commonly presents itself. In either case, the paralysis occurs in the opposite side of the *body*, as we should expect from the decussation of the Pyramids; but it may occur either on the same, or on the opposite side of the *face*,—the cause of which is not very apparent. If convulsions accompany the paralysis, we may infer that the Corpora Quadrigemina, or the parts below, are involved in the injury; and in this case it is usually found that the convulsions are on the paralyzed side of the body,—the effect of the lesion, both of the Cerebrum and of the Corpora Quadrigemina, being propagated to the opposite side by the decussation of the Pyramids. Where, as not unfrequently happens, there is paralysis of one side accompanying convulsions on the other, it is commonly the result of a lesion affecting the base of the Brain and Medulla Oblongata on the side on which the convulsions take place: here the effect of the lesion has to *cross* from the Brain, whilst its influence on the Medulla Oblongata is shown on the *same* side. Many anomalies present themselves, however, which are by no means easy of explanation, in the present state of our knowledge.—The disturbance

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* It is worthy of remark, that M. Flourens, who in the first instance maintained that sensation is altogether destroyed by the removal of the Cerebrum, has substituted, in the Second Edition of his Researches, the word *perception* for *sensation;* apparently implying exactly what is maintained above.

of the Cerebral functions occasioned by those changes in its nutrition which are commonly included under the general term Inflammation, presents a marked diversity of character according to the part it affects. Thus it is well known that the Delirium of excitement is usually a symptom of inflammation of the cortical substance or of the membranes of the Hemispheres. This is exactly what might be anticipated from the foregoing premises, since this condition is a perversion of the ordinary mental operations, which are dependent upon the instrumentality of the vesicular matter: and it is evidently impossible for the membranes to be affected with inflammation, without the nutrition of this substance being impaired, since it derives all its vessels directly from them. On the other hand, inflammation of the fibrous portion of the Cerebrum is usually attended rather with a state of torpor, than with excitement; and with diminished power of the will over the muscles. It is stated by Foville, that in acute cases of Insanity, he has usually found the cortical substance intensely red, but without adhesion to the membranes; whilst in chronic cases it is indurated and adherent: but where the insanity has been complicated with Paralysis, he has usually found the medullary portion indurated and congested.

560. The general result of such investigations is, that the Cerebrum is the instrument of all those *psychical* operations, which we include under the general term *Intellectual*, whilst it also affords, in part at least, the instrumental conditions of *Emotional* states; and that all those muscular movements which result from *voluntary* determinations, or which are directly consequent upon *emotional* excitement, have their origin in its vesicular substance, though the motor impulse is immediately furnished by the Cranio-Spinal apparatus, upon which the Cerebrum plays (§ 533). It does not hence follow, however, that the Cerebrum has such a direct relation to the Mind, that the consciousness is immediately and necessarily affected by changes taking-place in its own substance; and, however startling the proposition may at first sight appear, that the organ of the intellectual operations is not itself endowed with consciousness, a careful consideration of the relations of the Cerebrum to the Sensory Ganglia will tend to show that there is no *à priori* absurdity in such a notion. For if the connection of the vesicular matter of the Cerebral Hemispheres with the Sensorial Centres, be anatomically the same as that which exists between these centres and the Retina or any other peripheral expansion of vesicular matter in an organ of sense, which we have seen that it is (§ 549),—and if the same kind of change may be excited in the Sensorial Centres by an impression from each source, which has been shown to be a matter of common occurrence (§ 532),—it can scarcely be deemed unlikely that the Sensorial Centres should be the seat of consciousness, not merely for the impressions transmitted to them by the nerves of the external senses, but also for the impressions brought to them by the 'nerves of the internal senses,' as we may designate (after Reil) the radiating fibres of the Cerebral Hemispheres (§ 549). And there is on the other hand an *à priori* improbability that there should be *two* seats of consciousness, so far removed from one another as the Sensory Ganglia and the vesicular surface of the Hemispheres (for to their medullary substance no such attribute can be assigned with the least probability); an idea which is quite at variance with that very simple and familiar class of

phenomena, which consists in the *recollection of sensations.* For the remembered sensation is so completely the reproduction of the original, that we can hardly suppose the seat of the two to be different; yet the act of recollection is clearly Intellectual, and therefore Cerebral; consequently, if we admit that the Sensory Ganglia are the seat of the original sensation, we can scarcely but admit that they are also the seat of that which is reproduced by a Cerebral act,—a view which is fully confirmed by the occurrence of automatic movements as consequences of its recal (§ 532). And a careful analysis of our own mental operations will often supply evidence of the evolution of results, such as ordinarily proceed from intellectual action, without any consciousness on our own parts of the steps whereby these are attained.

561. Without presuming, then, to affirm positively what cannot be proved, it may be stated as a probable inference from the facts already referred-to, that the Sensory Ganglia constitute the seat of consciousness, not merely for impressions on the Organs of Sense, but also for changes in the cortical substance of the Cerebrum; so that, until the latter have reacted downwards upon the Sensorium, we have no consciousness either of the formation of ideas, or of any intellectual process of which these may be the subjects.—Ideas, Emotions, Intellectual operations, &c. have of late been frequently designated as 'states of consciousness;' and this psychological description of them is in full harmony with the physiological account here given of the material conditions under which they respectively occur. For as a Sensation is a state of consciousness excited through the instrumentality of the Sensorium, by a certain change (*e.g.*) in the condition of the Retina, it is not difficult to understand how a change in the condition of the Cerebrum may excite, through the same instrumentality, that state of consciousness which may be termed Ideational,* or that another change may produce the Emotional consciousness, another the Intuitional consciousness, another the Logical consciousness. And although it may be thought at first sight to be a departure from the simplicity of Nature, to suppose that the Cerebrum should require another organ to give us a consciousness of its operations, yet we have the knowledge that the Eye does not give us visual consciousness, nor the Ear auditory consciousness, unless they be connected with the Sensory Ganglia; and in the end (the Author feels a strong assurance) it will be found much simpler to accept the doctrine of a common centre for *sensational* and for what may be distinguished as *mental* consciousness, than to regard the two centres as distinct.†

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[*] The Author ventures to use this term, the meaning of which requires no explanation, on the authority of Mr. James Mill, who remarks,—"As we say Sensation, we might also say Ideation; it would be a very useful word; and there is no objection to it, except the pedantic habit of decrying a new term. Sensation is the general name for one part of our constitution [or rather, for one state of our consciousness], Ideation for another." ("Analysis of the Human Mind," vol. i. p. 42.)—If the use of the substantive Ideation be admitted, there can be no reasonable objection to the adjective *ideational.*

[†] It may serve to give additional confidence in the views above propounded, if the Author mentions that he was led by them to *predict* the psychological phenomena referred-to at the end of § 560, of which he was not at the time aware as facts, but of which he afterwards became assured by the analysis of his own consciousness, and by the communicated experience of others to whom he stated the question.—An interesting and suggestive paper by Mr. Lockhart Clarke, 'On the Nature of Volition,' will be found in the "Psychological Journal" for October, 1862.

6. *Of Sleep and Somnambulism.*

562. It is a peculiar feature in the physiology of the Cerebral and Sensorial Ganglia, that their activity undergoes a periodical suspension, more or less complete; the necessity for this suspension arising out of the fact that the exercise of their functions is in itself destructive to their substance, so that, if this be not replaced by nutritive regeneration, they speedily become incapacitated for further use. The interesting researches of Mr. Arthur Durham* on the condition of the circulation in the Brain during sleep, have shown that the brain is then in an essentially bloodless condition, and that not only the quantity but the rapidity of movement of the blood in the vessels is materially diminished; and this is corroborated by the observations of Dr. J. Hughlings Jackson on the ophthalmoscopic condition of the Retina during sleep,† the optic disc being then whiter, the arteries smaller, the veins somewhat larger, and the neighbouring part of the retina more anæmic, than in the waking state. In ordinary profound Sleep there is a state of complete unconsciousness, so far as *external* phenomena are concerned; no ordinary impressions upon the organs of sense being either felt or perceived; although an extraordinary impression, or even an habitual one upon which the attention has been previously fixed as that at which the slumberer is to awake himself (§ 569), occasions a renewal of sensorial activity. It is in this capability of being aroused by external impressions, that the chief difference lies between Sleep and the abnormal condition of Coma, whether this arise from the influence of pressure or effusion within the cranium, or be consequent upon the poisoning of the blood by narcotic substances, or follow a previous state of abnormal activity of the brain, such as Delirium. Between these two conditions, however, every gradation may be seen; as in the gradually-increasing torpor which results from slow effusion within the cranium, the gradual loss of susceptibility to external impressions which is observed after an over-dose of a narcotic, and the intensification of ordinary sleep which is consequent upon extreme previous fatigue. But it is a matter of doubt, whether the suspension of sensorial consciousness is equally complete as regards *internal* or Cerebral changes; for some are of opinion that, even in the most profound sleep, we still dream, although we may not remember our dreams; whilst others (and among these the Author would rank himself) consider that dreaming is a mark of imperfect sleep, and that, in profound ordinary sleep, the Cerebrum, in common with the Sensory Ganglia, is in a state of complete functional inactivity. When Dreaming takes place, there is usually a less complete exclusion of sensory impressions, although the perceptive consciousness may be entirely suspended; so that the course of the dream may be influenced by them, although the mind is not conscious of them as such (§ 574). If this be the true account of the case, we may consider that in profound Sleep the functional activity of the Cerebrum and of the Sensory Ganglia is alike suspended; but that in Dreaming the Cerebrum is partially active, whilst the Sensorium is in such a condition of recep-

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* "Guy's Hospital Reports," Third Series, vol. vi.

† See "Royal Lond. Ophth. Hosp. Reports."

tivity for Cerebral (subjective) impressions that the mind becomes directly conscious of them, though it only becomes conscious of (objective) impressions made upon the Organs of Sense, after their influence has been transmitted through it to the Cerebrum, and has been, as it were, reflected-back by that organ. It is, in fact, by their influence upon the current of *ideas*, and not by their power of exciting *sensations*, that we recognize their operation under such circumstances.

563. The state of Sleep is one to which there is beyond doubt a *periodical* tendency; for, when the waking activity has continued during a considerable proportion of the twenty-four hours, a sense of fatigue is usually experienced, which indicates that the brain requires repose; and it is only under some very strong physical or moral stimulus, that the mental energy can be sustained through the whole cycle. In fact, unless some decidedly abnormal condition of the Cerebrum be induced by the protraction of its functional activity, Sleep will at last supervene, from the absolute inability of the organ to sustain any further demands upon its energy, even in the midst of opposing influences of the most powerful nature.* That the strongest Volitional determination to remain awake is forced to give-way to Sleep, when this is required by the exhaustion of nervous power, must be within the experience of every one; and the only way in which the Will can even retard its access, is by determinately fixing the consciousness upon some definite object, and resisting every tendency in the thoughts to wander from this. It does not appear to be of any consequence, whether this exhaustion be produced by the active exercise of volition, reflection, emotion, or simple sensation; still we find that the *volitional* direction of the thoughts in a course different from that in which they tend spontaneously to flow, is productive of far more exhaustion than the automatic activity of the mind; whilst, on the other hand, the excess of *automatic* activity, whether as regards the intellectual operations or emotional excitement, tends to prevent sleep. This is particularly the case when the feelings are deeply interested; thus the strong desire to work-out a result, or to complete the survey of a subject, is often sufficient to keep-up the intellectual activity as long as may be requisite (a state of restlessness indeed being often induced, which prevents the access of sleep for some time longer); so, again, anxiety or distress is a most frequent cause of wakefulness; and it is generally to be observed that the state of *suspense* is more opposed to the access of sleep,

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* Thus it is on record, that, during the heat of the battle of the Nile, some of the over-fatigued boys fell asleep upon the deck: and during the last attack upon Rangoon, the Captain of one of the war-steamers most actively engaged, worn-out by the excess of continued mental tension, fell asleep, and remained perfectly unconscious for two hours, within a yard of one of his largest guns, which was being worked energetically during the whole period.—So even the severest bodily pain yields before the imperative demand occasioned by the continued exhaustion of the powers of the sensorial centres; thus Damiens slept upon the rack, during the intervals of his cruel sufferings; the North American Indian at the stake of torture will go to sleep on the least remission of agony, and will slumber until the fire is applied to awaken him; and the Medical Practitioner has frequent illustrations of the same fact.—That the continued demand for muscular activity is not incompatible with the access of sleep, is obvious from what has been already said of the persistence of the automatic movements in that condition; it is well known that, previously to the shortening of the hours of work, factory children frequently fell asleep whilst attending to their machines, although well aware that they should incur severe punishment by doing so.

than the greatest joy or the direst calamity when certainty has been attained.* But although an excess of automatic activity is opposed, so long as it continues, to the access of sleep, yet it cannot be long protracted without occasioning an extreme exhaustion of nervous power, which necessitates a long period of tranquillity for its complete restoration.

564. Whilst, however, the necessity for Sleep arises out of the state of the nervous system itself, there are certain external conditions which favour its access; and these, in common parlance, are termed its predisposing causes. Among the most powerful of these, is the *absence* of sensorial impressions; thus, darkness and silence usually promote repose; and the cessation of the sense of muscular effort, which takes-place when we assume a position that is sustained without it, is no less conducive to slumber. There are cases, however, in which the *continuance* of an accustomed sound is necessary, instead of positive silence, the cessation of the sound being a complete preventive of sleep; thus it happens that persons living in the neighbourhood of the noisiest mills or forges cannot readily sleep elsewhere. Such cases are referable either to the influence of *habit*, which causes the attention of the individual to be more attracted by the suspension of the sound than by its continuance; or to the fact that the *monotonous repetition* of sensorial impressions is often more favourable to sleep than their complete absence. Thus it is within the experience of every one, that the droning voice of a heavy reader on a dull subject is often a most effectual hypnotic; in like manner, the ripple of the calm ocean on the shore, the sound of a distant waterfall, the rustling of foliage, the hum of bees, and similar impressions upon the auditory sense, are usually favourable to sleep; and the muscular and tactile senses may be in like manner affected by an uniform succession of gentle movements, as we see in the mode in which nurses 'hush-off' infants, or in the practice of gently rubbing some part of the body which has been successfully employed by many who could not otherwise compose themselves to sleep. The reading of a dull book acts in the same mode through the visual sense; for the eyes wander-on from line to line, and from page to page, receiving a series of sensorial impressions which are themselves of a very monotonous kind, and which only tend to keep the attention alive in proportion as they excite interesting ideas.

565. In these and similar cases the influence of external impressions would seem to be exerted in withdrawing the mind from the distinct consciousness of its own operations (the loss of which is the transition-state towards that of complete unconsciousness), and in suspending the directing power of the Will. And this is the case, even where the attention is in the first instance *voluntarily* directed to them; as in some of the plans which have been recommended for the induction of sleep, when there exists no spontaneous disposition to it. In other methods, the attention is fixed upon some internal train of thought, which, when once set-going, may be carried-on automatically; such as counting numbers, or repeating a French, Latin, or Greek verb. In either case, when the sensorial consciousness has been once steadily fixed, the monotony of the

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* Thus it is a common observation, that criminals under sentence of death sleep badly so long as they entertain any hopes of a reprieve; but when once they are satisfied that their death is inevitable, they usually sleep more soundly, and this even on the very last night of their lives.

impression (whether received from the Organs of Sense, or from the Cerebrum) tends to retain it there; so that the Will abandons, as it were, all control over the operations of the mind, and allows it to yield itself up to the soporific influence. This last method is peculiarly effectual when the restlessness is dependent upon some mental agitation; provided that the Will has power to withdraw the thoughts from the exciting subject, and to reduce them to the tranquillizing state of a mere mechanical repetition.

566. The access of Sleep is sometimes quite sudden; the individual passing at once from a state of complete mental activity to one of entire torpor. More generally, however, it is gradual; and various intermediate phases may be detected, some of which bear a close resemblance to the state of Reverie. The same may be said with regard to the transition from the state of Sleep to that of wakeful activity; and this also may be sudden and complete, although it usually consists of a succession of stages,—the complete consciousness of the individual's relation to the external world, and the power of directing his thoughts and actions to any subject about which he may be required to exert himself, being the last to return to him. There may be a rapid alternation of these different states; the loss and recovery of the waking consciousness being many times repeated in the course of a few minutes, when the circumstances are such as to prevent the access of profound sleep by the recurrence of sensory impressions; as when a man on horseback, wearied from want of rest, lapses at every moment into a dozing state, from which the loss of the balance of his body as frequently and suddenly arouses him; or when a man going to sleep in a sitting posture, gradually loses the support of the muscles which keep his head erect, his head droops by degrees and at last falls forward on his chest, and the slight shock thence ensuing partially arouses and restores his voluntary power, which again raises the head. Similar fluctuations occur in the sensory perceptions; and these may be often artificially induced by very simple means. "We find, for example, one condition of sleep so light, that a question asked restores consciousness enough for momentary understanding and reply; and it is an old trick to bring sleepers into this state, by putting the hand into cold water, or producing some other sensation, not so active as to awaken, but sufficient to draw the mind from a more profound to a lighter slumber. This may be often repeated, sleep still going on; but make the sound louder and more sudden, and complete waking at once ensues. The same with other sensations. Let the sleeper be gently touched, and he shows sensibility, if at all, by some slight muscular movement. A ruder touch excites more disturbance and motion, and probably changes the current of dreaming; yet sleep will go on; and it often requires a rough shaking, particularly in young persons, before full wakefulness can be obtained." * * * "It is certain that the faculties of sensibility and volition are often unequally awakened from sleep. The case may be stated, familiar to many, of a person sleeping in an upright posture, with the head falling over the breast; in whom sensibility is suddenly aroused by some external impression, but who is unable, for a certain time, to raise his head, though the sensation produced by this delay of voluntary action is singularly distressing." These various cases, it is justly remarked by Sir H,

Holland,* depending severally on the intensity of sleep, and on the kind and degree of the external exciting causes, will be found to explain many of those so-called Mesmeric phenomena, which are offered to us under a widely different interpretation. And it may be here remarked, that among those intermediate states between sleep and waking, which either occur spontaneously, or can be induced in numerous individuals by very simple processes, there are several which exhibit peculiarities that are not in themselves in the least degree less remarkable, than are those which are regarded with so much wonder by the uninformed observer, when induced by the asserted Mesmeric influence, and paraded as specimens of its power.

567. It is unquestionable that the supervention of Sleep may be promoted by the strong previous expectation of it; and this is true, not merely of ordinary sleep, but of the states of artificial Reverie and Somnambulism formerly described. Every one knows the influence of habit, not only in regard to 'time,' but also as to 'place and circumstance,' in predisposing to Sleep. Thus, the celebrated pedestrian Capt. Barclay, when accomplishing his extraordinary feat of walking 1000 miles in as many successive hours, obtained at last such a mastery over himself that he fell asleep the instant he lay down. And the sleep of soldiers, sailors, and others, who are prevented by 'duty' from obtaining regular periods of repose, but are obliged to take their rest at short intervals, may be almost said to come at command; nothing more being necessary to induce it, than the placing the body in an easy position, and the closure of the eyes. It is related that the Abbé Faria, who acquired notoriety through his power of inducing somnambulism, was accustomed merely to place his patient in an arm-chair, and then, after telling him to shut his eyes and collect himself, to pronounce in a strong voice and imperative tone the word "dormez," which was usually successful. The Author has had frequent opportunities of satisfying himself, that the greater success which attended the 'hypnotic' mode of inducing somnambulism, in the hands of Mr. Braid, its discoverer, than in that of others, partly lay in the mental condition of his subjects, who came to him for the most part under the confident expectation of its production, and were further assured by a man of very determined will, that it *could not* be resisted.† And it is one of the most curious phenomena of the state of induced Reverie, absurdly called 'biological,' that, in many subjects at least, sleep may be induced in a minute or less, by the positive assurance, with which the mind of the individual becomes possessed, that it *will* and *must* supervene.

568. The influence of previous mental states is yet more remarkable, in determining the effects produced upon the sleeper by different sensory impressions. The general rule is, that *habitual* impressions of any kind have much less effect in arousing the slumberer, than those of a new or unaccustomed character. An amusing instance of this kind has been related to the Author, which, even if not literally true, serves extremely

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* See his excellent Chapter on 'Sleep,' from which the above extracts are taken, in his "Medical Notes and Reflections," and his "Chapters on Mental Physiology."

† A very amusing instance in which Sleep, having been previously induced by the ordinary 'mesmeric' and then by the 'hypnotic' processes, was brought-on by the simple belief that a new process was being put in practice, will be found in the "Brit. and For. Med. Rev.," vol. xix. p. 477.

well as an illustration of what is unquestionably the ordinary fact. A gentleman who had taken his passage on board a ship of war, was aroused on the first morning by the report of the morning gun, which chanced to be fired just above his berth; the shock was so violent as to cause him to jump out of bed. On the second morning, he was again awoke, but this time he merely started and sat-up in bed; on the third morning, the report had simply the effect of causing him to open his eyes for a moment, and turn in his bed; on the fourth morning, it ceased to affect him at all; and his slumbers continued to be undisturbed by the report, so long as he remained on board. It often happens that sleep is terminated by the *cessation* of an accustomed sound, especially if this be one whose monotony or continuous repetition had been the original inducement to repose. Thus, a person who has been read or preached to sleep, will awake, if his slumber be not very profound, on the cessation of the voice; and a naval officer, sleeping beneath the measured tread of the watch on deck, will awake if that tread be suspended.—In this latter case, the influence of the simple cessation of the impression will be augmented by the circumstance next to be alluded-to, which has received too little attention from writers on this subject, but which is of peculiar interest both in a physiological and psychological point of view, and is practically familiar to almost every one.

569. The awakening power of sensory impressions is greatly modified by our *habitual state of mind* in regard to them. Thus, if we are accustomed to *attend* to these impressions, and our perception of them is thus *increased* in acuteness, we are much more easily aroused by them, than we are by others which are in themselves much stronger, but which we have been accustomed to disregard. Thus, most sleepers are aroused by the sound of their own names uttered in a low tone, when it requires a much louder sound of a different description to produce any manifestation of consciousness. The same thing is seen in comatose states; a patient being often found capable of being momentarily aroused by shouting his name into his ear, when no other sound produces the least effect.—The following circumstance, communicated to the Author by the late Sir Edward Codrington, is a most apposite illustration of this principle. When a young man, he was serving as signal-lieutenant under Lord Hood, at the time when the French fleet was confined in Toulon harbour; and being desirous of obtaining the favourable notice of his commander, he devoted himself to his duty (that of watching for signals made by the look-out frigates) with the greatest energy and perseverance, often remaining on deck nineteen hours out of the twenty-four, with his attention constantly directed towards this one object. During the few hours which he spent in repose, his sleep was so profound that no noise of an ordinary kind, however loud, would awake him; and it used to be a favourite amusement with his comrades, to try various experiments devised to test the soundness of his sleep. But if the word 'signal' was even whispered in his ear, he was instantly aroused, and fit for immediate duty.—The influence of habitual attention is shown as much in the effect produced by the cessation, as in that of the occurrence, of sensory impressions. Thus in the case of the naval officer aroused by the suspension of the measured tread of the watch over his head, the knowledge possessed during the waking state, that this suspension is either an act of

negligence which requires notice, or indicates some unusual occurrence, doubtless augments the effect which the discontinuance of the sound would of itself produce.

570. It is not requisite, however, that the sound should be one habitually attended to during the hours of watchfulness; for it is sufficient if it be one on which the *attention has been fixed* as that at which the slumberer is to arouse himself. Thus the medical man, even in his first profound sleep after a fatiguing day's work, is aroused by the first stroke of the clapper of his night-bell; and to those who are accustomed to rise every morning at the sound of an alarum-clock, the frequency and regularity of the occurrence do not diminish, but rather increase, the readiness with which it produces its effect, provided that the warning be promptly obeyed. On this usually depends the efficiency of the awakening sound; if it be disregarded as a thing to which there is no occasion to give heed, it very soon ceases to produce any effect, the entire peal not being sufficient to awake the sleeper; whilst, on the other hand, the first stroke is enough to break the repose of him who is impressed with the effectual desire of profiting by the warning. And thus it may happen that, of two persons in the same room, either shall be at once aroused by a sound which produces no disturbance in the slumbers of the other. To this influence of previous impressions, whether habitual, or but once forcibly made, we are also to refer the spontaneous termination of the state of sleep at particular times, without any sensorial excitement from external impressions. Thus, many persons who are accustomed to rise at a particular hour, wake regularly at that hour, whether they have gone to rest early or late; so that the act of spontaneously awakening is no proof that the desirable amount of repose has been obtained. But what is more remarkable is, that many individuals have the power of determining, at the time of going to rest, the hour at which they shall rise, so as to awake from a profound sleep at the precise time fixed-upon. In others, however, the desire to rise at a particular hour only induces a state of restlessness throughout the night, destroying the soundness of the slumbers: the individual awakes many times in the night, with the belief that the hour is past, and very possibly oversleeps it after all, the system being worn-out by the need of repose.

571. The *Amount of Sleep* required by Man is affected by so many conditions, especially *age*, *temperament*, *habit*, and *previous exhaustion*, that no general rule can be laid-down on the subject.—The condition of the *fœtus in utero* may be regarded as one of continual slumber; the apparatus of Animal life being completely secluded from all stimuli which could arouse it into activity, whilst the energy of the Organic functions is entirely directed to the building-up of the fabric. On its first entrance into the world, the infant continues to pass the greater part of its time in slumber; and this is particularly to be noticed in cases of premature birth, the seven months' child seeming to awake only for the purpose of receiving food, and giving but little heed to external objects, whilst even the eight months' child is considerably less alive to sensory impressions than one born at the full time. The excess of activity of the *constructive* over the *destructive* operations, which characterizes the whole period of infancy, childhood, and adolescence (CHAP. XVIII.), requires that a larger proportion of the diurnal cycle shall be passed in sleep (during which the

former may be carried-on without hindrance), than is requisite when adult age has been attained, the two sets of changes being then balanced; and the amount of sleep to which the system shows itself disposed, gradually diminishes from three-fourths to one-half, and from one-half to one-third, or even to one-quarter, of the twenty-four hours. It is to be noticed that the sleep of children or young persons is not only longer than that of adults, but is also more profound. On the other hand, as age advances, and the bodily and mental activity of the waking state decreases, a smaller amount of sleep suffices; or, if the slumber be protracted, it is usually less deep and refreshing. It may be noticed, however, that very old persons usually pass a large proportion of their time in sleep, or rather in a sort of heavy doze, especially after meals; as if, in consequence of the want of energy of their nutritive operations, a very long period of repose is necessary to repair the waste which takes place during their short period of activity.—In regard to the influence of *temperament*, it may be remarked that a plethoric habit of body, sustained by full diet, usually predisposes to sleep, provided that the digestive powers be in a vigorous condition; persons of this constitution frequently pass nine or ten hours in slumber, and maintain that they cannot be adequately refreshed by less. On the other hand, thin wiry people, in whom the 'nervous' temperament predominates, usually take comparatively little sleep, notwithstanding the greater activity of their nervous system when they are awake; but their slumber, while it lasts, is generally very deep. Persons of 'lymphatic' temperament, heavy passionless people, who may be said to live very slowly, are usually great sleepers; but this is rather because, through the dulness of their perceptions, they are less easily kept awake by sensorial or mental excitement, than because they really require a prolonged cessation of activity. As they are half asleep during the waking state, so would it appear that the constructive operations must be far from active while they are asleep, so little do they seem restored by the repose.—The amount of sleep, *cæteris paribus*, required by individuals, is very greatly influenced by *habit*; and, contrary to what we might anticipate, we find that the briefest sleepers have usually been men of the greatest mental activity. Thus Frederick the Great and John Hunter are said to have only required five hours' sleep out of the twenty-four; and General Elliot, celebrated for his defence of Gibraltar, is recorded not to have slept more than four hours out of the twenty-four. It may be doubted whether it would be possible for any one to sustain a life of vigorous exertion upon a smaller allowance than this; and the general fact is, that from six to eight hours of repose, out of every twenty-four, are required to keep the system of an adult in a state of healthful activity. The influence of habit may be brought to bear on the protraction, as well as on the abbreviation, of the usual period. Thus Quin, the celebrated actor, could slumber for twenty-four hours successively; and Dr. Reid, the metaphysician, could take as much food, and afterwards as much sleep, as were sufficient for two days.—It is needless to dwell upon the obvious fact, that, other things being equal, the amount of sleep required by man is proportional to the *amount of mental exertion* put-forth during the waking hours; since this is an obvious result of what has been laid-down as the cause of the demand for sleep. It may be remarked, however, that we must not measure the *amount* of sleep by its *duration* alone:

since its *intensity* is a matter of equal importance. The light slumber which is disturbed by the slightest sounds, cannot be as renovating as the profound sopor of those whom no ordinary noise will awake.

572. There are certain states of the Encephalic centres, in which there is an *entire absence of Sleep;* and this may continue for many days, or even for weeks or months. Insomnia is, for instance, one of the characteristics of acute Mania, and may also exist in various forms of Monomania; it is usually, also, one of the symptoms of incipient meningeal inflammation; and it may constitute a specific disease in itself. In all these cases, however, the preponderance of the *destructive* processes over the *constructive* manifests itself, sooner or later, in the exhaustion of the mental and bodily powers. Thus Mania, when prolonged or frequently recurring, subsides into Dementia; and, if it continue for any length of time, is sure to be followed by a great sense of wretchedness and prostration, frequently accompanied by continual restlessness. Such effects, too, in a less aggravated degree, result from habitual *deficiency* of sleep; whether this be due to emotional excitement which keeps repose at bay, or to a voluntary determination to keep the intellect in activity. This is a very common occurrence among industrious students, who, with a laudable desire for distinction, allow themselves less than the needed quantum of repose. Headache, tension, heat, throbbing, and various other unpleasant sensations in the head, give warning that the brain is being overtasked; and if this warning be not taken, sleep, which it was at first difficult to resist, becomes even more difficult to obtain; a state of general restlessness and feverish excitement is induced; and if, in spite of this, the effort be continued, serious consequences, in the form of cerebral inflammation, apoplexy, paralysis, fever, insanity, or loss of mental power, more or less complete, are nearly certain to be induced. Some individuals can sustain such an effort much longer than others, but it is a great mistake to suppose that they are not equally injured by it; in fact, being possessed with the belief that they are not suffering from the exertion, they frequently protract it, until a sudden and complete prostration gives a fearful demonstration of the cumulative effects of the injurious course in which they have been persevering. Those, consequently, who are earlier forced to give-way, are frequently capable of accomplishing more in the end.—In regard to the degree of *protraction* of sleep which is consistent with a healthy state of the system in other respects, it is difficult to speak with certainty. Of the numerous well-authenticated instances on record,* in which sleep has been continuously prolonged for many days or even weeks, it is enough here to state that they cannot be regarded as examples of natural sleep; the state of such persons being more closely allied to hysteric coma. An unusual tendency to ordinary sleep generally indicates a congested state of the brain, tending to apoplexy; and it has been stated that apoplexy has been actually induced by the experimental attempt to ascertain how large a proportion of the diurnal cycle might be spent in sleep.—Thus, on either side, inattention to the dictates of Nature, in respect to the amount of sleep required for the renovation of the system, becomes a source of disease, and should therefore be carefully avoided.

573. *Dreaming.*—We have hitherto spoken of Sleep in its most com-

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* Such, for example, as that of Samuel Chilton ("Phil. Trans.," 1694), and that of Mary Lyall ("Trans. of Roy. Soc. of Edinb.," 1818).

plete or profound form; that is, the state of complete unconsciousness. But with the absence of consciousness of external things, there may be a state of mental activity of which we are more or less distinctly cognizant at the time, and of which our subsequent remembrance in the waking state varies greatly in completeness. The chief peculiarity of this state of *dreaming* appears to be, that there is an entire suspension of Volitional control over the current of thought, which flows on automatically, sometimes in a uniform coherent order, but more commonly in a strangely incongruous sequence. The former is most likely to occur when the mind simply takes-up the train of thought on which it had been engaged during the waking-hours, not long previously; and it may even happen that, in consequence of the freedom from distraction resulting from the suspension of external influences, the Reasoning processes may thus be carried-on during sleep with unusual vigour and success, and the Imagination may develope new and harmonious forms of beauty.* The more general fact is, however, that there is an entire want of any ostensible coherence between the ideas which successively present themselves to the consciousness; and yet we are completely unaware of the incongruousness of the combinations which are thus formed. It has been well remarked that "nothing surprises us in dreams." All probabilities of 'time, place, and circumstance' are violated; the dead pass before us as if alive and well; even the sages of antiquity hold personal converse with us; our friends upon the antipodes are brought upon the scene, or we ourselves are conveyed thither, without the least perception of the intervening distance; and occurrences, such as in our waking state would excite the strongest emotions, may be contemplated without the slightest feeling of a painful or pleasurable nature. Facts and events long since forgotten in the waking state, and remaining only as latent impressions on the Cerebrum, present themselves to the mind of the dreamer; and many instances have occurred, in which the subsequent retention of the knowledge thus re-acquired has led to most important results.† But one of the most remarkable of all the peculiarities in the state of dreaming, is the *rapidity* with which trains of thought pass through the mind; for a dream in which a long series of events has seemed to occur, and a multitude of images has been successively raised-up, has been often certainly known to have occupied only a few minutes, or even seconds, although whole years may seem to the dreamer to have elapsed. There would not appear, in truth, to be any limit to the amount of thought which may thus pass through the mind of the dreamer, in an interval so brief as to be scarcely capable of measurement; as is obvious from the fact, that a dream involving a long succession of supposed events, has often distinctly originated in a sound which has also awoke the sleeper, so that the whole must have passed during the almost inappreciable period of transition between the previous state of sleep and the full waking consciousness.* Hence it has been argued by some, that *all* our dreams really take place in the momentary passage between the states of sleeping and waking; but such an idea is not consistent with the fact, that the course of a dream may often be traced by observing the successive changes of expression in the countenance of the dreamer. It seems, however, that those dreams are most distinctly remembered in the waking state which have passed through the mind during the transitional phase just alluded-to; whilst those which occur in a state more allied to Somnambulism, are more completely isolated from the ordinary consciousness.—There is a phase of the dreaming state which is worthy of notice as marking another gradation between this and the vigilant state; that, namely, in which the dreamer has a consciousness that he is dreaming, being aware of the unreality of the images which present themselves before his mind. He may even make a voluntary and successful effort to prolong them if agreeable, or to dissipate them if unpleasing; thus evincing the possession of a certain degree of that directing power, the entire want of which is the characteristic of the true state of Dreaming.

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* Thus, Condorcet saw in his dreams the final steps of a difficult calculation which had puzzled him during the day; and Condillac tells us that, when engaged in his "Cours d'Etude," he frequently developed and finished a subject in his dreams, which he had broken-off before retiring to rest. Coleridge relates of himself that his fragment "Kubla Khan" was composed during sleep, which had come upon him whilst reading the passage in "Purchas's Pilgrimage," on which the poetical description was founded, and was written-down immediately on awaking, "the images rising up before him as things, with a parallel production of the correspondent expressions, without any sensation or consciousness of effort."

† See a number of such cases in Dr. Abercrombie's "Inquiries concerning the Intellectual Powers."

574. But the sensibility to external impressions may not be entirely suspended in Dreaming; and it is curious that even where sensations are not recognized by the mind of the dreamer as proceeding from external objects, they may affect the course of its own thoughts; so that the character of the dreams may be in some degree predetermined by such an arrangement of sensory impressions as is likely to modify them. This is especially the case in regard to the dreamy state induced by certain narcotics, such as the Hachisch (a preparation of *Cannabis Indica*), employed for this purpose in the East; for the emotional condition of the individual under its influence is entirely under the control of external impressions; so that those who give themselves up to the intoxication of the *fantasia*, take care to withdraw themselves from everything which could give their delirium a tendency to melancholy, or excite in them anything else than feelings of pleasurable enjoyment.† Moreover, there are certain forms of ordinary Dreaming, in which the whole succession of thought and feeling (which is made manifest by the words occasionally uttered, or by the play of countenance, or by the more active movements of the dreamer) may be governed by external suggestion; as, for example, in the well-known case of the officer who amused his friends by acting his dreams during the expedition to Louisburgh, the course of these dreams being capable of direction by whispering into the sleeper's

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* The only phase of the waking state, in which any such intensely-rapid succession of thoughts presents itself, is that which is now well attested as a frequent occurrence, under circumstances in which there is imminent danger of death, especially by drowning; the whole previous life of the individual seeming to be presented instantaneously to his view, with its every important incident vividly impressed on his consciousness, just as if all were combined in a picture, the whole of which could be taken-in at a glance.

† See the Author's article, 'Sleep,' in the "Cyclop. of Anat. and Phys.," vol. iv. pp. 688-690; and Moreau, "Du Hachisch et de l'Aliénation Mentale, Etudes Psychologiques," p. 67.

ear, especially if this was done by a friend with whose voice he was familiar.* Such forms of Dreaming constitute a transition to the state of Somnambulism.

575. *Somnambulism.*—The phenomena of Somnambulism are so various, that it is difficult to give any general definition that shall include the whole; but it is a condition which is common to all forms of this state, that the controlling power of the Will over the current of thought is entirely suspended, and that all the actions are directly prompted by the ideas which possess the mind; and the differences chiefly arise out of the mode in which the succession of ideas is directed, this being in some cases a coherent sequence through the whole of which some one dominant impression may be traced, whilst in other instances it is more or less completely determinable by external suggestions. These two forms are thus parallel to the states of spontaneous Abstraction and artificial Reverie (Electro-Biology) respectively; but differ from them both in this essential feature,—that they occur in a state of consciousness so far distinct from the ordinary waking condition, as not to be connected with it by the ordinary link of Memory; and that although the course of thought in Somnambulism usually manifests the directing influence of previous habits, and the knowledge of persons and things possessed during the waking state may be readily brought before the mind, yet nothing which occurs during the state of Somnambulism is ever retraced spontaneously, or can be brought back by an act of recollection. Impressions upon the nervous system, however, are sometimes left by strong emotional excitement, which give-rise to subsequent feelings of discomfort, of whose origin the individual is entirely unconscious.†—In the first of the phases just referred-to, a train of reasoning is often carried-out with remarkable clearness and correctness, and its results expressed in appropriate language, or otherwise acted-on. Thus, a mathematician may work-out a difficult problem, an orator may make a speech appropriate to the occasion on which he supposes himself to be called-up, or an author may compose and commit to writing poetry or prose, upon the subject which occupies his thoughts. But it is a frequent defect of the intellectual operations carried-on in this condition, that, through the complete absorption of the attention by one set of considerations, no account is taken of others which ought to modify the conclusion; and this, although it may be palpably inconsistent with the teachings of ordinary experience, is not felt to be so, unless the latter should happen to present themselves unbidden to the thoughts.

576. The second of the phases above mentioned, which is especially seen in the *artificial* Somnambulism induced by the (so-called) *Mesmeric* process, or by the fixed gaze at a near object (as practised by Mr. Braid under the name of *Hypnotism*), is essentially the same as that of the 'biological' condition, save in the different relation which they respec-

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* This case is detailed by Dr. Abercrombie ("Inquiries concerning the Intellectual Powers," 5th ed., p. 277), on the authority of Dr. Gregory, to whom it was related by a gentleman who witnessed it. A case of a very similar nature, the subject of which was a medical student at Edinburgh, is related in Smellie's "Philosophy of Natural History."

† See a very curious example of this kind, which fell under the Author's own observation, narrated in the article 'Sleep,' in the "Cyclop. of Anat. and Phys.," vol. iv. p. 693.

tively bear to the waking state; for there is the same readiness to receive new impressions through the senses (the visual sense, however, being generally in abeyance), and the same want of persistence in any one train of ideas, the direction of the thoughts being entirely determined by the suggestions which are introduced from without. In either of these extreme forms of Somnambulism, and in the numerous intermediate phases which connect the two, the consciousness seems entirely given-up to the one impression which is operating upon it at the time; so that whilst the attention is exclusively directed upon any object, whether actually perceived through the senses, or brought suggestively before the mind by previous ideas, nothing else is felt. Thus there may be complete insensibility to bodily pain, the somnambulist's whole attention being given to what is passing in his mind; yet in an instant, by directing the attention to the organs of sense, the anæsthesia may be replaced by ordinary sensibility; or, by the fixation of the attention on any one class of sensations, these shall be perceived with most extraordinary acuteness, whilst there may be a state of complete insensibility as regards the rest.—Thus, the Author has witnessed a case in which such an exaltation of the sense of Smell was manifested, that the subject of it discovered without difficulty the owner of a glove placed in his hand, in an assembly of fifty or sixty persons; and in the same case, as in many others, there was a similar exaltation of the sense of Temperature. The exaltation of the Muscular Sense, by which various actions that ordinarily require the guidance of vision, are directed independently of it, is a phenomenon common to the 'mesmeric' with various other forms of artificial as well as of natural Somnambulism. The Author has repeatedly seen Mr. Braid's 'hypnotized' subjects write with the most perfect regularity, when an opaque screen was interposed between their eyes and the paper, the lines being equidistant and parallel; and it is not uncommon for the writer to carry back his pen or pencil to dot an *i* or cross a *t*, or make some other correction in a letter or word. Mr. B. had one patient who would thus go back and correct with accuracy the writing on a whole page of note-paper; but if the paper was moved from the position it had previously occupied on the table, all the corrections were on the *wrong* points of the paper as regarded the *actual* place of the writing, though on the *right* points as regarded its *previous* place; sometimes, however, he would take a fresh departure, by feeling for the upper left-hand corner of the paper, and all his corrections were then made in their right positions, notwithstanding the displacement of the paper.—So, again, when the attention of the somnambulist is fixed upon a certain train of thought, whatever may be spoken in harmony with this is heard and appreciated; but what has no relation to it, or is in discordance with it, is entirely disregarded.

577. It is among the most curious of the numerous facts which Mr. Braid's investigations upon artificial Somnambulism have brought to light, that the suggestions derived from the 'muscular sense' have a peculiar potency in determining the current of thought. For if the face, body, or limbs be brought into an attitude that is expressive of any particular emotion, or that corresponds with that in which it would be placed for the performance of any voluntary action, the corresponding

mental state,—that is, either an Emotional condition affecting the general direction of the thoughts, or the Idea of a particular action,—is called-up in respondence to it. Thus, if the hand be placed upon the vertex, the Somnambulist will frequently, of his own accord, draw his body up to its fullest height, and throw his head slightly back; his countenance then assumes an expression of the most lofty pride, and the whole train of thought is obviously under the domination of this feeling; as is manifested by the replies which the individual makes to interrogatories, and by the tone and manner in which these are delivered. Where the first action does not of itself call-forth the rest, it is sufficient to straighten the legs and spine, and to throw the head somewhat back, to arouse the emotion, with its corresponding manifestation, in its full intensity. If, during the most complete domination of this emotion, the head be bent forwards and the body and limbs be gently flexed, the most profound humility then takes its place. So, again, if the angles of the mouth be gently separated from one another, as in laughter, a hilarious disposition is immediately generated; and this may be made to give place to moroseness, by drawing the eyebrows towards each other and downwards upon the nose, as in frowning.* So, again, if the hand be raised above the head, and the fingers be flexed upon the palm, the idea of climbing, swinging, or pulling at a rope is called-up in such as have been used to such kinds of exertion; if, on the other hand, the fingers be flexed when the arm is hanging-down at the side, the idea suggested is that of lifting a weight; and if the same flexure be made when the arm is advanced forwards in the position of striking a blow, the idea of fighting is at once aroused, and the Somnambulist is very apt to put it into immediate execution.†

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* The Author has not only repeatedly witnessed all these effects, as produced by Mr. Braid upon 'hypnotized' subjects, of whom several had never been previously in that condition, and had no idea whatever of what was expected from them; but he has been assured by a most intelligent medical friend, who has paid special attention to the psychological part of this inquiry, that having subjected himself to Mr. Braid's practice, and having been only partially thrown into the 'hypnotic' state (in fact, 'biologized'), he distinctly remembers everything that was done, and can retrace the uncontrollable effect upon his emotional state, which was produced by this management of his muscular apparatus.

† On one occasion on which the Author witnessed this result, a violent blow was struck, which chanced to alight upon a second somnambulist within reach; *his* combativeness being thereby excited, the two closed, and began to belabour one another with such energy, that they were with difficulty separated. Although their passions were at the moment so strongly excited, that even when separated they continued to utter furious denunciations against each other, yet a little discreet manipulation of their muscles soon calmed them and restored them to perfect good-humour.

CHAPTER XII.

OF THE ORGANS OF THE SENSES, AND THEIR FUNCTIONS.

1. *Of Sensibility in General.*

578. We have seen that the conscious Mind is affected by impressions made upon the corporeal organism,—or, in other words, that Sensation is produced,—through the instrumentality of a certain part of the Encephalon termed the *Sensorium*, which is the general centre of the nerves both of 'special' and of 'common' sensibility; the former connect it with the special Organs of Sense, the latter with the body generally, to the several parts of which they are by no means uniformly distributed, some tissues being altogether destitute of them. Those parts of the body which are endowed with sensory fibres, and impressions on which, therefore, give rise to sensation, are ordinarily spoken-of as *sensible;* and different parts are said to be sensible in different degrees, according to the strength of the sensation produced by a corresponding impression on each. In accordance with the general fact of the dependence of all Nervous action on the continuance of the Circulation of the blood, it is found that the sensory nerves are distributed pretty much in the same proportion as the blood-vessels: that is to say, in the non-vascular tissues, —such as the epidermis, hair, nails, cartilage, and bony substance of the teeth,—no nerves exist, and there is an entire absence of sensibility; and in those whose vascularity is trifling, as is the case with bones, tendons, ligaments, fibrous membranes, and other parts whose functions are simply mechanical, and even with serous and areolar membranes, there are few nerves, and the sensibility is dull. Many of these textures are acutely sensible, however, under certain circumstances; thus, although tendons and ligaments may be wounded, burned, &c., without much consciousness of the injury being aroused, they cannot be stretched without the production of considerable pain; and the fibrous, serous, and areolar tissues, when their vascularity is increased by inflammation, also become extremely susceptible of painful impressions. All very vascular parts, however, do not possess acute sensibility; the muscles, for instance, are furnished with a large supply of blood, to enable them to perform their peculiar function; but they are not sensible in by any means the same proportion. Even the substance of the brain, and of the nerves of special sensation, appears to be destitute of this endowment; and the same may be said of the mucous membranes lining the interior of the several viscera, which, in the ordinary condition, are much less sensible than the membranes that cover those viscera, although so plentifully supplied with blood for their especial purposes. The most sensible of all parts of the body is the Skin, in which the sensory nerves spread themselves out into a minute network; and even of this tissue, the sensibility differs greatly in different parts (§ 584).—The organs of *Special* Sensation become, by the peculiar character of the nerves with which they are supplied, the recipients of impressions of a particular kind: thus, the Eye is sensible to light, the Ear to sound, &c.; and whatever amount of *ordinary* sensibility they

possess, is dependent upon other sensory nerves. The eye, for example, contrary to the usual notions, is a very insensible part of the body, unless affected with inflammation, for though the mucous membrane which covers its surface, and which is prolonged from the skin, is acutely sensible to tactile impressions, the interior is by no means so, as is well known to those who have operated much on this organ. And the common sensory nerves which supply certain parts of the body, are adapted to receive and convey to the mind impressions of particular kinds, with much greater readiness than they communicate those of a different description, thus the sensibility to tickling is much greater on some parts of the surface than on others, and this kind of excitement, applied to the genitals or to the nipple, produces sensations of a most peculiar order

579 An active Capillary Circulation being essential to the sensibility of every part supplied with nerves, any cause which retards this deadens the sensibility, as is well seen with regard to Cold, and, on the other hand, an increase in its energy produces a corresponding increase in the sensibility, as is peculiarly evident in the 'active congestion' which usually precedes and accompanies Inflammation A diminution or increase of sensibility to external impressions may arise, however, not only from an abnormal state of the circulation in the organ or part itself, but from the similar conditions affecting that part of the Sensorium in which the impressions are received Thus in those various conditions of the Encephalon, in which either a stagnation of the circulation, or an abnormal state of the blood (such as that produced by anæsthetic agents), occasions a diminished functional activity in the Sensorial centres, this is marked by obtuseness to sensory impressions, on the other hand, in active congestion of the brain, the most ordinary external impressions produce sensations of an unbearable violence, and in that peculiar condition of the nervous system known under the name of Hysterical, the patients often manifest the same hyperæsthesia, even when the circulation is in a feeble, rather than in an excited state * It is remarkable that the sensibility of the mucous membranes lining the internal organs, is less exalted by the state of inflammation, than is that of most other parts, and in this arrangement we may trace a wise and beneficent provision, since, were it otherwise, the functions necessary to life could not be performed without extreme distress, whenever a very moderate amount of disorder might exist in the viscera If a joint is inflamed, we can give it rest, but to the actions of the alimentary canal we can give little voluntary respite

580 It is through the medium of Sensation, that we acquire a knowledge of the material Universe around us, by the psychical operations which its changes excite in ourselves The various kinds or modes of Sensation *suggest* to us various ideas regarding the properties of matter; and these properties are known to us, only through the changes which they produce in the several organs It is well known that instances exist, in which,

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* The influence of toxic agents introduced into the blood, in producing Anæsthesia and Hyperæsthesia, constitutes a very wide field of inquiry, the investigation of which has been ably commenced by Dr Anstie, in his interesting work on Stimulants and Narcotics (London, 1864) It is remarkable that *Lead* and *Alcohol* should be capable of inducing either of these states

from some imperfection of the organization, there is an incapacity for distinguishing colours or musical tones, whilst there is no want of sensibility to light or sound; and that some persons are naturally endowed with a much greater range of the sensory faculties, than that possessed by others. Hence it does not seem at all improbable, that there are properties of matter of which none of *our* senses can take immediate cognizance; and which other beings might be formed to perceive, in the same manner as *we* are sensible to light, sound, &c. Thus many animals are affected by atmospheric changes, in such a manner that their actions are regarded by Man as indications of the probable state of the weather; and the same is the case in a less degree with some of our own species, who are peculiarly susceptible of the like influences.—Now the most universal of all the qualities or properties of Matter, on which, in fact, our notion of it is chiefly founded, is its occupation of space, producing a more or less complete *resistance* to displacement; and this quality is that through which alone any knowledge of the external world can be obtained by a large proportion of the lower Animals; *contact* between their own surface and some material body, being required to produce sensation. We shall presently see, however, that the idea of the *shape* of a body which we form from the touch, results from a very complex process, such as animals of the lower grades can scarcely be supposed to exercise. There can be little doubt that, next to the mere sense of resistance, sensibility to *temperature* is the most universally diffused through the Animal kingdom; and probably the consciousness of *luminosity* is the next in the extent of its diffusion.* It is probable that the sense of *taste* (which has a close affinity to that of touch) exists very low down in the animal scale, being obviously of great importance in the selection of food; but the Anatomist has no means of ascertaining where this refinement exists, and where it does not; since the organs of taste and touch are very similar. The sense of *hearing* does not seem to be distinctly present among the Invertebrate animals, except in such as approach most nearly to the Vertebrata; it is not improbable, however, that sonorous vibrations may produce an effect upon the system of those animals which do not receive them as *sound.* The sense of *smell*, which is concerned with one of the least general properties of matter, appears to be the least-widely diffused among the whole; being only possessed in any high degree by Vertebrated animals, and being but feebly present in a large proportion of these.

581. Besides the various kinds of sensibility which have been just enumerated, there are others which are ordinarily associated together, along with the sense of material resistance (and its several modifications), and the sense of temperature, under the head of Common Sensation; but several of them, especially those which originate in the body itself, can scarcely be regarded in this light. Such are the feelings of hunger

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* There is good reason to believe, from observation of their habits, that many animals are susceptible of the influence, and are directed by the guidance, of *light*, whose organs are not adapted to receive true visual impressions, or to form optical images; and such would seem to be the function of the red spots, frequently seen on prominent parts of the lower Articulata and Mollusca, and even of some Radiata. Wherever these are of sufficient size to allow their structure to be examined, they are found to be largely supplied with nerves, but to be destitute of the peculiar organization which alone constitutes a true *eye*.

and thirst; that of nausea; that of distress resulting from suspended aeration of the blood; that of 'sinking at the stomach,' as it is vulgarly but expressively described, which results from strong mental emotion; the sexual sense, and perhaps some others.—Now in regard to all these, it is impossible in the present state of our knowledge to say, whether their peculiarity results from the particular constitution of the nerves that receive and convey them, or only from a modification of the impressing causes, from the particular endowments of their ganglionic centres, and from the mode in which they operate. Thus we have no evidence whether the nervous fibrils which convey from the lungs the sense of distress resulting from deficient aeration, are of the same or of a different character from those which convey from the surface of the air-passages the sense of the contact of a foreign body. But as we know that all the trunks along which these peculiar impressions travel, do minister to ordinary sensation, whilst the nerves of truly 'special' sensation are not sensible to tactile impressions, it is evident that the probability seems in favour of the identity of the fibres which minister to these sensations, with those of the usual sensory character. We shall see that with regard to the sense of Temperature, there is strong evidence that its peculiarity depends on the speciality of the apparatus by which impressions are received at the peripheral extremities of the tactile nerves, rather than upon any peculiarity in the transmitting fibres.

582. There are certain external agencies which can excite changes in the Sensorium through several different channels; the sensation being in each case characteristic of the particular nerve on which the impression is made. Thus pressure, which produces through the nerves of common sensation the feeling of resistance, is well known to occasion, when exerted on the eye, the sensation of light and colours; and, when made with some violence on the ear, to produce 'tinnitus aurium.' It is not so easy to excite sensations of taste and smell by mechanical irritation; and yet, as was shown by Dr. Baly,* this may readily be accomplished in regard to the former. The sense of nausea may be easily produced, as is familiarly known, by mechanical irritation of the fauces. Electricity still more completely possesses the power of affecting all the sensory nerves with the changes which are peculiar to them; for, by proper management, an individual may be made conscious at the same time of flashes of light, of distinct sounds, of a phosphoric odour, of a peculiar taste, and of pricking sensations, all excited by the same cause, the effects of which are modified by the respective peculiarities of the instruments through which it operates.—But although there are some stimuli which can produce sensory impressions on all the nerves of sensation, it will be found that those to which any one organ is *peculiarly* fitted to respond, produce little or no effect upon the rest. Thus the ear cannot distinguish the slightest difference between a luminous and a dark object. A tuning-fork, which, when laid upon the ear whilst vibrating, produces a distinct musical tone, excites no other sensation when placed upon the eye, than a slight jarring feeling. The most delicate touch cannot distinguish a substance which is sweet to the taste, from one which is bitter; nor can the taste (if the communication between the mouth and the nose be cut-off) perceive any-

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* Translation of Müller's "Elements of Physiology," p. 1062, *note*.

from some imperfection of the organization, there is an incapacity for distinguishing colours or musical tones, whilst there is no want of sensibility to light or sound; and that some persons are naturally endowed with a much greater range of the sensory faculties, than that possessed by others. Hence it does not seem at all improbable, that there are properties of matter of which none of *our* senses can take immediate cognizance; and which other beings might be formed to perceive, in the same manner as *we* are sensible to light, sound, &c. Thus many animals are affected by atmospheric changes, in such a manner that their actions are regarded by Man as indications of the probable state of the weather; and the same is the case in a less degree with some of our own species, who are peculiarly susceptible of the like influences.—Now the most universal of all the qualities or properties of Matter, on which, in fact, our notion of it is chiefly founded, is its occupation of space, producing a more or less complete *resistance* to displacement; and this quality is that through which alone any knowledge of the external world can be obtained by a large proportion of the lower Animals; *contact* between their own surface and some material body, being required to produce sensation. We shall presently see, however, that the idea of the *shape* of a body which we form from the touch, results from a very complex process, such as animals of the lower grades can scarcely be supposed to exercise. There can be little doubt that, next to the mere sense of resistance, sensibility to *temperature* is the most universally diffused through the Animal kingdom; and probably the consciousness of *luminosity* is the next in the extent of its diffusion.* It is probable that the sense of *taste* (which has a close affinity to that of touch) exists very low down in the animal scale, being obviously of great importance in the selection of food; but the Anatomist has no means of ascertaining where this refinement exists, and where it does not; since the organs of taste and touch are very similar. The sense of *hearing* does not seem to be distinctly present among the Invertebrate animals, except in such as approach most nearly to the Vertebrata; it is not improbable, however, that sonorous vibrations may produce an effect upon the system of those animals which do not receive them as *sound*. The sense of *smell*, which is concerned with one of the least general properties of matter, appears to be the least-widely diffused among the whole; being only possessed in any high degree by Vertebrated animals, and being but feebly present in a large proportion of these.

581. Besides the various kinds of sensibility which have been just enumerated, there are others which are ordinarily associated together, along with the sense of material resistance (and its several modifications), and the sense of temperature, under the head of Common Sensation; but several of them, especially those which originate in the body itself, can scarcely be regarded in this light. Such are the feelings of hunger

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* There is good reason to believe, from observation of their habits, that many animals are susceptible of the influence, and are directed by the guidance, of *light*, whose organs are not adapted to receive true visual impressions, or to form optical images; and such would seem to be the function of the red spots, frequently seen on prominent parts of the lower Articulata and Mollusca, and even of some Radiata. Wherever these are of sufficient size to allow their structure to be examined, they are found to be largely supplied with nerves, but to be destitute of the peculiar organization which alone constitutes a true *eye*.

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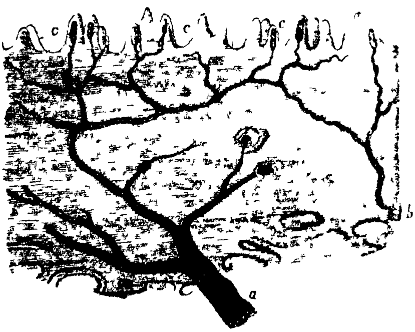
* Translation of Müller's "Elements of Physiology," p. 1062, *note.*

thing peculiar in the most strongly-odoriferous bodies.—It may hence be inferred that no nerve of *special* sensation can, by any possibility, take-on the function of another.

2. *Sense of Touch.*

583. By the sense of Touch, as commonly understood, is meant that modification of the common sensibility of the body, of which the Cutaneous surface is the especial seat. The Skin is peculiarly adapted for this purpose, not merely by the large amount of sensory nervous fibres which are distributed in its substance, but also by its possession of a papillary apparatus in which these nerves for the most part terminate, or rather commence. The *papillæ* are little elevations of the surface of the cutis, usually simply-conical or clavate in form (Fig. 122), but sometimes presenting numerous summits. On the palmar surface of the hand, they are arranged in rows; and they are there so numerous, that (according to E. H. Weber) as many as 81 compound, or from 150 to 200 simple papillæ, are contained within the area of a square (Paris) line. The papillæ are also very numerous, though without any definite arrangement, on the red surface of the lips, on the penis of the male, on the labia minora and clitoris of the female, and on the nipples of both sexes; but elsewhere they are scattered more widely apart. Each sensory papilla receives one or more nerve-fibres from the plexus which is formed by the inosculation of the ramifications of the cutaneous nerves (Fig. 122); and these nerve-fibres seem to terminate (at least in the papillæ of the palm of the hand and of the lips, and in the simple papillæ of the tongue) in a peculiar 'axile body,' which occupies the principal part of the interior of the papilla (Fig. 123). With regard to the nature of this body, there has been considerable discussion between Prof. Wagner, its discoverer, and Prof. Kolliker:* the former regarding it as an organ altogether *sui generis*; whilst the latter maintains that it is nothing else than a mass of homogeneous connective tissue with an external layer of imperfectly-developed elastic tissue, and

Fig 122



Vertical Section of the *Skin* of the palmar surface of the fore-finger (treated with a solution of caustic soda), showing the branches of cutaneous nerves, *a*, *b*, inosculating to form a terminal plexus, of which the ultimate ramifications pass into the cutaneous papillæ, *c*, *c*, *c*.

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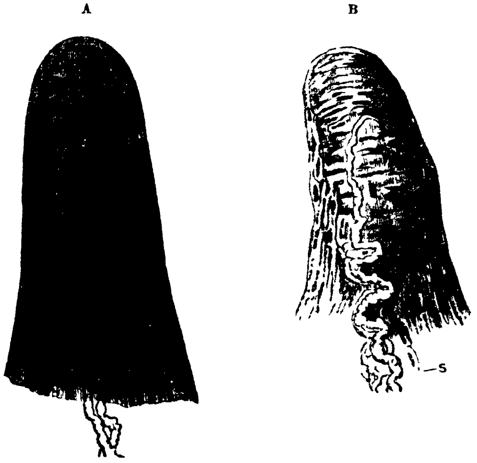
* See Prof. Wagner in the Gottingen "Gelehrte Nachrichten" for Feb. 1852, and "Müller's Archiv," 1852, heft 4; and Prof. Kolliker in "Zeitschrift für Wissenschaftliche Zoologie," June, 1852, and in his "Mikroskopische Anatomie," band ii. p. 24. See also Dalzell, in "Edinb. Monthly Journ.," March, 1853; Ecker, "Icon. Physiol.," plate xvii.; Leydig, "Müller's Archiv," 1856, p. 50; Gerlach, "Mikroskop. Studien," Erlangen, 1858; Krause, "Die Terminal Korperchen der Einfach Sensibeln Nerven," Hanover, 1860; Huxley, in "Cyclop. of Anat. and Physiology," Supplement, Art. 'Tegumentary Organs,' 1859, p. 508; Meissner, "Beiträge," plate i. figs. 6 and 8; Henle, "Handbuch der Systemat. Anatomie," 1862, band ii. p. 18; Fick, "Lehrbuch

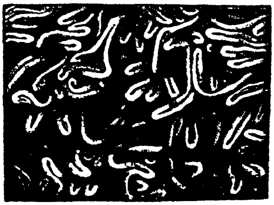
that it is essentially similar to the bundles of fibrous tissue encircled by elastic fibres, which are to be found in the substance of the cutis. This last view is in the main supported by Mr. Huxley, who regards the 'axile body' as formed by the continuation and increased development of the neurilemma of the nerve-tubes which enter the papilla, and as bearing a close relation to the 'Pacinian bodies.'* A very simple form of the axile bodies has been described by Krause as occasionally occurring in the conjunctiva, lips and soft palate, in the tongue, and in the glans penis and glans clitoridis. Here the nerve forms a "terminal button or knob," consisting of a delicate sheath dotted with nuclei and filled with granular plasma, into which the cylinder axis of the nerve enters, terminating by a simple blunt extremity. In the Pacinian bodies, a more complex structure is met with than in either of those just mentioned, the chief difference being that instead of a single sheath, there are many investing capsules; a space being, however, always left between the innermost one and the extremity of the nerve, in which a fluid or semi-fluid substance is contained. Dr. Beale† appears to doubt the termination in any instance of sensory nerves by free extremities; for he has everywhere obtained demonstrative evidence of a network, the fibres being often of extraordinary tenuity. He believes that in the papillæ of the Skin, and even in the Pacinian bodies, after becoming connected with nuclei or corpuscles the nerve-fibres turn or loop back to the cell from whence they originate. That the axile corpuscles of Wagner are intimately associated with proper nervous tissue, is clearly shown by the fatty degeneration they undergo on section of the nerves supplying them. It was maintained by Wagner, that the papillæ which contain the axile bodies, and

Fig. 123.



Tactile Papillæ from the Skin of the palmar surface of the fore-finger, showing the *tactile corpuscles* or 'axile bodies':—A, in the natural state; B, treated with acetic acid.

Fig. 124.



Capillary loops in *Cutaneous papillæ* at margin of lips.

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* See his Memoir 'On the Structure and Relation of the Corpuscula Tactus,' in the "Quarterly Journal of Microscopical Science," vol. ii. p. 1.

† Beale's "Archives of Medicine," vol. iii. p. 236.

to which nerve-fibres proceed, contain no blood-vessels save by coalescence with a vascular papilla; whilst the vascular papillæ which contain capillary loops (Fig. 124), constitute a distinct order, containing no nerve-fibres. This, however, is denied by Prof. Kölliker; who asserts that the corpusculated papillæ of the palm of the hand often contain vessels, whilst the vascular papillæ of the lip contain nerves. Mr. Huxley states (loc. cit.) that in the human finger he has met with corpusculated papillæ containing vascular loops, though rarely.—The question must be regarded as still open to investigation; the undoubted association of capillary loops and nerve-tubes in the fungiform papillæ of the Tongue (§ 592) rendering it improbable that there should be a complete dissociation of them in the tactile papillæ of the Skin; whilst, on the other hand, the presence of a true (vascular) papillary structure where a thick epidermis has to be formed, as on the sole of the foot or the matrix of the nail, seems to indicate that the vascular papillæ of the palm of the hand may probably be destined rather to this office, than to participate in sensibility. As the 'axile' and 'Pacinian bodies' are only to be found in the papillæ of those parts which are distinguished for acuteness of tactile sensibility, we cannot regard them as *essential* to the exercise of the sense of touch; their function probably being to *intensify* tactile impressions, where delicacy of touch is peculiarly required.*

584. The relative sensibility of different parts of the Skin may be in some degree judged-of by the results of the observations of Prof. E. H. Weber;† whose mode of ascertaining it was to touch the surface with the legs of a pair of compasses, the points of which were guarded with pieces of cork, and then (the eyes being closed) the legs were approximated, until they were brought within the smallest distance at which they could be felt to be distinct from one another, which has been termed by Dr. Graves 'the limit of confusion.'—The following are some of the measurements thus taken:—

Point of tongue	½ of a line.
Palmar surface of third phalanx	1 line.
Red surface of lips	2 lines.
Palmar surface of second phalanx	2 ,,
Palmar surface of metacarpus	3 ,,
Tip of the nose	3 ,,
Dorsum and edge of tongue	4 ,,
Part of lips covered by skin	4 ,,
Palm of hand	5 ,,
Skin of cheek	5 ,,
Extremity of great toe	5 ,,
Hard palate	6 ,,
Dorsum of hand	8 ,,
Mucous membrane of gums	9 lines.
Lower part of forehead	10 ,,
Lower part of occiput	12 ,,
Back of hand	14 ,,
Vertex	15 ,,
Skin over patella	16 ,,
——— sacrum	18 ,,
——— acromion	18 ,,
Dorsum of foot	18 ,,
Skin over sternum	20 ,,
Skin beneath occiput	24 ,,
Skin over spine, in back	30 ,,
Middle of the thigh	30 ,,

It is curious that the distance between the legs of the compasses, as well as the rapidity of their motion when they were lightly drawn over the skin, seemed to be greater (although really so much less), when it was felt by the more sensitive parts, than when it was estimated by parts of less distinct sensibility. With the extremities of the fingers and the point of the tongue, the distance could be distinguished most easily in the longitudinal direction; on the dorsum of the tongue, the face, neck, and extremities, the distance could be recognized best when the points were placed transversely. As a general fact, it seems that the sensibility of the trunk is greater on the median line, both before and behind, and less at the sides. Differences in the temperature and weight of bodies, were, according to Prof. Weber's observations, most accurately recognized at the parts which were determined to be most sensible by the foregoing method of inquiry.*—It has been since found, however, by Prof. Valentin, who has followed-up and extended Prof. Weber's observations, that a considerable amount of individual variation exists in regard to the 'limit of confusion;' some persons being able to distinguish the points at one-half or even one-third of the distances required by others. Czermak† has drawn attention to many curious facts in relation to the "sense of space," or "locality" possessed by the skin; and has particularly shown that two points may be much more closely approximated, and yet distinguished as two, if they are applied one after the other, than if they are applied together. The delicacy of the sense of touch is diminished if the skin be either artificially or naturally stretched; hence the skin of the belly is less sensitive during pregnancy than under ordinary circumstances, and this may also in some measure serve to explain the diminution in sensibility which occurs in the passage from childhood to adult age, though the difference is no doubt partially due to the increased thickness of the epithelium. The theory of the sense of touch which has been suggested by Fick, is that each nerve-fibril breaks up into a pencil of fine filaments at the periphery, which are distributed over a certain space, perhaps on the average about 1-25th of an inch in diameter. An impression made upon any one of these filaments conveys the same sensation to the sensorium, providing no other nerve be distributed to the same space; but this hardly ever occurs, and hence compound sensations arise, by which our perception of the precise spot of the skin touched by a point is accurately determined. Thus if we suppose the distribution of nerves to be represented by the circles A, B, C, (Fig. 125) single sensations would be produced if a point were applied at 1, 2, or 3, but a compound sensation would be produced if contact were made at 4 or 5, for the fibrils of two nerves, A and C, or B and C, would be

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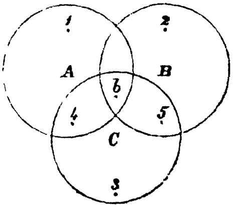
* In proof of which, various ingenious experiments have been made by Krause (see "Zeitschrift für Rat. Med.," xvii. p. 278). He explains their presence in the mesentery of the Cat as connected with the mechanism and arrangement of the viscera required for the act of springing.

† For similar experiments performed by Dr. Ballard, see "Lancet," 1862, vol. i. p. 303. Dr. B. found that in the hand the tip of the index finger was the most, the dorsal surface of the base of the fifth metacarpal bone the least, sensitive part; the limit of confusion in the former being 0·35 of a line, in the latter 5 lines.

FIG. 125.



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* See his Memoir "De Pulsu, Respiratione, Auditu, et Tactu," Lipsiæ, 1834. See also "Recherches sur la Nature, la Distribution, et l'Organe du Sens Tactile," by M. H. Belfield-Lefèvre, Paris, 1837; and Prof. Valentin's "Lehrbuch der Physiologie des Menschen," band ii. § 566.—In the Author's article 'Touch' in the "Cyclopædia of Anatomy and Physiology," vol. iv. p. 1169, will be found a Table including the whole series of observations made by Profrs. Weber and Valentin, the *maxima* and *minima* of the latter being stated, as well as the *means*.

† "Sitzungsberichte der Wiener Akad.," band xvii. p. 563, band xxiv. p. 231; and "Moleschott's Untersuch.," band i. p. 188.

implicated; whilst if the impression were made at 6, a still more complex sensation would arise, for then the peripheral branches of these nerves would be affected. It is obvious that the closer these 'sensory circles' are, and the more intimately the branches of different nerves are intercalated with one another, the greater will be the accuracy of the sense of locality of that part, or, in other words, the greater will be the facility with which minute differences in the precise spot touched will be appreciated.

585. As already stated (§ 580), the only idea communicated to our minds by the sense of Touch, when exercised in its simplest form, is that of *Resistance*; and it is by the various degrees of resistance which the sensory surface encounters, of which we partly judge by the muscular sense (§ 524), that we estimate the hardness or softness of the body against which we press. It is only when either the sensory surface or the substance touched is made to change its place in regard to the other, that we obtain the additional notion of *extension* or *space*; this also being derived from the combination of the muscular with the tactile sense. By the impressions made upon the papillæ, during the movement of the tactile organ over the body which is being examined, the roughness, smoothness, or other peculiar *characters of the surface* of the latter are estimated. Our knowledge of *form*, however, is a very complex process, requiring not merely the exercise of the sense of touch, but also great attention to the muscular sensations.—It is chiefly, as formerly remarked, in the *variety* of movements of which the hand of Man is capable, that it is superior to that of any other animal; and it cannot be doubted that the sense of Touch thus employed, affords us a very important means of acquiring information in regard to the external world, and especially of correcting many vague and fallacious notions which we should derive from the sense of Sight, if used alone. On the other hand, it must be confessed that our knowledge would have a very limited range, if this sense were the only medium through which we could acquire ideas. It is probably on the sensations communicated through the Touch, that the idea of the material world, as something external to ourselves, chiefly rests; but this idea is by no means a logical deduction from our experience of these sensations, being rather an instinctive or intuitive perception directly excited by them.

586. Various experimenters* have endeavoured to determine the accuracy with which the Skin can appreciate impressions of weight or pressure when unassisted by the 'muscular sense,' that is, when the part experimented-on is well supported, as when the hand is laid upon a table. Aubert and Kammler found that on the face and dorsal surface of the upper extremity, the pressure of a portion of elder-pith, presenting a surface of nearly one-third of an inch square, and weighing only 1-33rd of a grain (2 Mgrm.), could be distinguished; whilst the tips of the fingers required a weight, presenting the same superficies, of 1-3rd of a grain or more, and the toes as much as 8 grains, before any sensation of pressure was felt. The presence of the minute hairs on the face was, however, found materially to influence its sensibility, since when these were shaved off it was much diminished.—According to Weber, differences in the amount of pressure are more accurately distinguished if they are applied successively

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* Aubert and Kammler, "Moleschott's Untersuch.," band v. p. 145; Dohrn, "Zeits. f. Rat. Med.," 1860.

to the same point, than if they are estimated coetaneously. The interval, however, must not be more than a few seconds, unless the difference be considerable. Thus when 4 ounces and 5 ounces were successively applied, an accurate judgment of the difference might be made after 90 seconds; but the difference between 14·5 and 15 ounces could not be accurately determined after 40 seconds. If the bare sense of pressure were assisted by the muscular sense, as in cases when the hand was unsupported, much finer discrimination was always displayed. Thus on lifting a cloth in which weights were concealed, Weber found that ten people correctly indicated that a weight of 80 ounces was heavier than one of 78 ounces. Both Weber and Fechner* appear to have satisfactorily shown that with light weights smaller differences are perceived than with heavy weights. Thus supposing that *ounce* weights are distinguishable in the ratio of 29 to 30,—*i.e.*, that a weight of 29 ounces can be discriminated when attentively examined from one of 30 ounces, a whole ounce requiring to be added or subtracted before certainty is attained;—when *drachms* are employed the same ratio still subsists, only that in this instance the removal or addition of one drachm to a weight of 30 drachms can be accurately appreciated. Meissner has drawn attention to the fact, which must be familiar to most persons, that if the hand or foot be immersed in warm water or mercury, the only sensation experienced is that of a ring surrounding the limb at the surface of the fluid. This effect is, as he suggests, probably due to the circumstance that the pressure is applied in such cases with perfect uniformity over the part immersed, and therefore causes no disturbance of the nervous elements, the tactile sense being only excited at the line where the pressure produced by the fluid is exchanged for that of the air.—Valentin† has endeavoured to ascertain the duration of a momentary excitation of the sense of Touch by rolling a spiked wheel over the skin; when slowly rotated, the contact of each spike was clearly discerned; but when only 1-640th of a second intervened between the successive blows, they could no longer be distinguished.—That the conditions under which certain of the modifications of common sensation operate, are in some respects different from those of ordinary Touch, is very easily shown. Thus, the feeling of tickling is excited most readily in parts which have but a low tactile sensibility, namely, the armpits, flanks, and soles of the feet; whilst in the points of the fingers, whose tactile sensibility is most acute, it cannot be excited. Moreover, the nipple is very moderately endowed with ordinary sensibility; yet by a particular kind of irritation, a very strong feeling may be excited through it.—Again, in regard to Temperature, it is remarked by Weber that the left hand is more sensitive than the right; although the sense of touch is undoubtedly the most acute in the latter. He states that if the two hands, previously of the same temperature, be plunged into separate basins of warm water, that in which the left hand is immersed will be felt as the warmer, even though its temperature is somewhat lower than that of the other. In regard to the sensations of heat and cold, he points-out another curious fact,—that a weaker impression made on a large surface, seems more powerful than a stronger impression made on a small surface; thus, if the forefinger of one hand be immersed in water at 104°, and the whole of the other hand be plunged in water at 102°, the cooler water will be thought the warmer; whence the well-known fact, that water in which a finger can be held, will scald the whole hand. Hence it also follows, that minute differences in temperature, which are imperceptible to a single finger, are appreciated by plunging the whole hand into the water; in this manner a difference of one-third of a degree may readily be detected, when the same hand is placed successively in two vessels. The judgment is more accurate, when the temperature is not much above or much below the usual heat of the body; just as sounds are best discriminated, when neither very acute nor very grave.

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* "Elemente der Psychophysik," 1860.

† 'Ueber die Dauer der Tasteindrücke,' "Archiv f. Physiol. Heilk.," band xi. p. 438.

587. Some further experiments have also been made by Prof Weber,* to determine whether the sense of Temperature is received through any other channel than the sensory apparatus contained in the integuments.—The first means of which he availed himself for deciding this question, was that afforded by the results of accident or surgical operations, in which a portion of skin had been left deficient. Thus, in three cases in which a large portion of the skin had been destroyed by a burn, and in which healing had not advanced so far as to renew the organ of touch, it was found that no correct discrimination could be made between two spatulas, one of them at a temperature of from 48° to 54°, the other of from 113° to 122°, which were brought into contact with the denuded surface; so that one of these patients thrice affirmed that he was being touched with the cold body, when it was warm, and the reverse. But when the spatula was in one instance made somewhat warmer, and was brought into contact with the unskinned surface, the patient felt not *heat* but *pain*.—Another means of gaining information on this point, is afforded by the ingestion or injection of a large quantity of warm or cold fluid into the stomach or intestinal canal. Thus Professor Weber states that after drinking a tumbler of water at 32°, he felt the cold water in the mouth, in the palate, and in the pharynx, as far as the limits of the sense of touch; but the gradual passage of the cold water into the stomach could not be perceived. There was, it is true, a slight sensation of cold in the gastric region; but as it only occupied the situation of the anterior wall of the stomach, it was attributable to the abstraction of heat from the abdominal integuments in contact with this. In an opposite experiment, that author drank quickly three glasses of milk, the temperature of the first of which was 158°, that of the second 145°, whilst that of the third was intermediate between the two. The sensation of heat could not be traced lower-down than that of the cold in the previous experiment. At the moment when the fluid entered the stomach, there was a feeling which remained for some time, but which could not be distinguished as heat, being mistakeable for cold. In order to ascertain the sensation produced in the large intestine by cold water, an injection of 14 ounces of water of the temperature of 65° was thrown up the rectum; but scarcely any sensation of cold could be perceived from it. In another instance, 21 ounces of water at the same temperature were thus injected, without any resulting sensation of cold. In both these cases, on the return of the enema a few minutes afterwards, a distinct feeling of cold was experienced at the anus. When water of so low a temperature as 45½° was injected, the first feeling excited was a sensation of cold in the immediate neighbourhood of the

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* "Muller's Archiv," 1849, heft iv. s. 278–283.

anus, and then a feeble movement in the bowels; but a little time afterwards, there was a faint sensation of cold, especially in the anterior wall of the abdomen. This sensation, however, remained after the return of the water; and may hence be attributed to the abstraction of warmth from the abdominal integuments, which was proved to have taken place, the temperature of the surface being lowered 3°. So, again, if the cavity of the nose be filled with cold water, the coldness is only perceived in the parts of the cavity which are most endowed with the proper tactile sense, namely, the neighbourhood of the nostrils and of the pharynx; and it is not at all discernible in the higher part of the cavity, which is especially subservient to the olfactory sense. But when the water injected is very cold (*e.g.* 41°), a peculiar pain is felt in the upper part of the nasal fossæ, extending to the regions of the forehead and the lachrymal canals; this pain, however, is altogether different from the sense of coldness.

588. From the foregoing experiments it appears fair to conclude, that the sensory nerves have no power of receiving impressions indicative of difference of Temperature, unless those impressions are communicated through a special organ; but they afford no adequate ground for the supposition, that a set of nerve-fibres is provided for their transmission distinct from those which minister to common sensation. This conclusion is confirmed by the fact, that we cannot excite impressions of heat or cold by direct application to the trunks of nerves which we know must conduct such impressions: for the parts of the skin, immediately beneath which lie large nerve-trunks, are not more sensitive to moderate heat or cold than are any others; whilst a greater degree of either is felt as pain, not as a change of temperature. Thus, a mixture of ice and water applied over the ulnar nerve, affects it in fifteen seconds, and produces severe pain, having no resemblance to cold, and such as cannot be excited by the same degree of cold applied to any other region. So the nerve of the tooth-pulp is equally and similarly affected by water of 43° and of 112°; either application causing a pain exactly similar to that excited by the other, or to that produced by pressure. The same is true of the impressions received through the skin itself, when they pass beyond certain limits of intensity; thus, the sensation produced by touching frozen mercury is said to be not distinguishable from that which results from touching a red-hot iron. Wunderli* and Fick, moreover, found that sensations of heat even in the most sensitive parts of the body were sometimes mistaken for those of contact. Thus in the case of the hand, an erroneous conclusion was arrived at six times out of 105 trials, and on the back twelve times in 30 experiments.†

589. The improvement in the sense of Touch, in those persons whose dependence upon it is increased by the loss of other senses, is well known; and the remarkable circumstance noticed by Volkmann,‡ that the increased sensitiveness which results from frequent experiments made upon one side of the body is experienced also in the nerve-fibres distributed to the oppo-

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* Henle and Meissner's "Bericht," 1859, p. 632.

† For observations tending to show that the sensations of touch are conveyed by channels distinct from those which conduct painful impressions, see Sieveking, "Med.-Chir. Rev.," 1858, p. 280.

‡ Volkmann, 'Über der Einfluss der Übung auf das Erkennen Raümlicher Distanzen,' "Bericht der Sachs. Gesell.," 1858.

site and exactly symmetrical parts, seems to show that the improved delicacy of the sense is to be in part attributed (as already remarked) to the increased attention which is given to the sensations, and in part, it may be surmised, to an increased development of the tactile organs themselves, resulting from the frequent use of them. The process of the acquirement of the power of recognizing elevated characters by the touch, is a remarkable example of this improveability. When a blind person first commences learning to read in this manner, it is necessary to use a large type; and every individual letter must be felt for some time, before a distinct idea of its form is acquired. After a short period of diligent application, the individual becomes able to recognize the combination of letters in words, without forming a separate conception of each letter; and can read line after line, by passing the finger over each, with considerable rapidity. When this power is once thoroughly acquired, the size of the type may be gradually diminished; and thus blind persons may bring themselves, by sufficient practice, to read a type not much larger than that of an ordinary large-print Bible. The case of Saunderson, who, although he lost his sight at two years old, became Professor of Mathematics at Cambridge, is well known; amongst his most remarkable faculties, was that of distinguishing genuine medals from imitations, which he could do more accurately than many connoisseurs in full possession of their senses. Several instances are recorded, of men who became eminent as Sculptors after the loss of their sight, and who were particularly successful in modelling portrait-busts; here, it is obvious, not merely the *tactile* but the *muscular* sensibility must be greatly augmented in acuteness by the habit of attending to it. The power of immediate recognition of individuals by the slightest contact of the hands, even after long periods of time, which most blind and deaf persons have displayed, is one of the most curious examples of the mode in which tactual perceptions will impress themselves on the memory, when they are habitually attended-to. As an example of the correct notions which may be conveyed to the mind, of the forms and surfaces of a great variety of objects, and of the sufficiency of these notions for accurate comparison, the Author may mention the case of a blind friend of his own, who has acquired a very complete knowledge of Conchology, both recent and fossil; and who is not only able to recognize every one of the numerous specimens in his own cabinet, but to mention the nearest alliances of a shell previously unknown to him, when he has thoroughly examined it by his touch. Many similar instances might be cited, one of the most remarkable being that of John Gough, who, though blind, was a noted botanical collector, and earned his livelihood as a land-surveyor. Several cases are on record,* of the acquirement, by the blind, of the power of distinguishing the *colours* of surfaces which were similar in other respects; and, however wonderful this may seem, it is by no means incredible. For it is to be remembered, that the difference of colour depends upon the position and arrangement of the particles composing the surface, which render it capable of reflecting one ray whilst it absorbs all the rest; and it is quite consistent with what we know from other sources, to believe that the sense of Touch may become so refined, as to communicate a perception of such differences.*

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* Among the best-authenticated of these, is that of a lady who became blind, and afterwards deaf, in consequence of an attack of confluent small-pox; cited in Dr. Kitto's "Lost Senses," vol. ii. p. 79, from the "Annual Register" for 1758.—Dr. Kitto's treatise may be referred-to, as containing a large collection of interesting cases of a similar description.

3. *Sense of Taste.*

590. The sense of Taste is that by which we distinguish the *sapid* properties of bodies. The term, as commonly understood, includes much more than this; being usually employed to designate the whole of that knowledge of the qualities of a body (except such as is purely tactile), which we derive through the sensory apparatus situated within the mouth. But it will be hereafter shown that a considerable part of this is dependent upon the assistance of the *olfactive* sense (§ 594); which is affected, through the posterior nares, by the odorous emanations of all such bodies as are capable of giving them off; and the indications of which are so combined with those of the true gustative sense, as to make an apparently single impression upon the Sensorium. Moreover, there are certain sensorial impressions received through the organ of taste, which are so nearly allied in their character to those of *touch*, as to render it difficult to specify any fundamental difference between them; such are the *pungent* sensations produced by mustard, pepper, the essential oils, &c.; all of which substances, when applied for a sufficient length of time to any part of the cutaneous surface, produce a sensation which can scarcely be distinguished from that excited through the organ of taste, in any other way than by its inferior intensity, and by the absence of the concurrent odorous emanations. The *taste* of such substances might therefore, perhaps, be considered as the composite result of the impressions made upon the sensorium through a refined and acute *touch*, and by the effect of their odorous emanations upon the organ of *smell*. After making full allowance, however, for all such as can be thus accounted-for, there remains a large class of pure *sapors*, of which we take cognizance without the assistance of smell, and which are altogether dissimilar to any tactile impressions; such are the *bitter* of quinine, the *sour* of tartaric acid, the *sweet* of sugar, the *saline* of common salt, &c. The smell can give us no assistance in distinguishing small particles of these bodies, since they are either entirely inodorous, or so nearly so as only to be recognizable through its means when in large masses; and the most refined touch cannot afford any indication of that kind of difference among them, of which we are at once rendered cognizant by taste.—Of all the 'special' senses, however, that of Taste is most nearly allied to that of touch, as appears from several considerations. In the first place, the *actual contact* of the object of sense with the organ through which the impression is received, is necessary in the present case, as in the preceding. Again, it appears from the considerations formerly adduced (§ 480), that there is no special nerve of Taste; for the gustative impressions upon the front of the tongue are conveyed by the Lingual branch of the Fifth pair, whilst those made upon the back of the organ are conveyed by the Glosso-pharyngeal, both of which nerves also minister to common sensibility; and pressure on

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* For some additional details in regard to the sense of Touch, see the Author's article 'Touch' in the "Cyclopædia of Anatomy and Physiology," vol. iv.

the trunk of either of these nerves gives-rise to pain, which is not the case with either the olfactory, the optic, or the auditory nerves. Moreover, the papillary apparatus, through which the gustative impressions are made upon the extremities of these nerves, is essentially the same in structure with that of the skin.*

591. For the Gustative nerve-fibres to be impressed by the distinctive properties of sapid substances, it appears requisite that these substances should be brought into immediate relation with them, and that they should penetrate, in the state of solution, through the investments of the papillæ, into their substance. This would seem to be proved by the two following facts: first, that every substance, whether solid, fluid, or gaseous, which possesses a distinct taste, is more or less soluble in the fluids of the mouth, whilst substances which are perfectly insoluble do not make their presence known in any other way than through the sense of touch; and, second, that if the most sapid substance be applied in a dry state to the papillary surface, and this be also dry, no sensation of taste is excited. Hence it may be inferred that in the reception of gustative impressions, a change is produced in the molecular condition of the nerve-fibres, or, to use the language of Messrs. Todd and Bowman, their polarity is excited by the direct agency of the sapid matter itself. This change may be induced, however, both by electrical and by mechanical stimulation. If we make the tongue form part of a galvanic circuit, a peculiar sensation is excited, which is certainly allied rather to the gustative than to the tactile, and which does not seem to be due (as was at one time supposed) to the decomposition of the salts of the saliva. And, as Dr. Baly has pointed-out,† "if the end of the finger be made to strike quickly, but lightly, the surface of the tongue at its tip, or its edge near the tip, so as to affect not the substance of the organ, but merely the papillæ, a taste sometimes acid, sometimes saline, like the taste produced by electricity, will be distinctly perceived. The sensation of taste thus induced will sometimes continue several seconds after the application of the mechanical stimulus." On the other hand, as Wagner has truly remarked, if the surface of the tongue near the root be touched with a clean dry glass rod, or a drop of distilled water be placed upon it, a slightly bitterish sensation is produced; and this, if the pressure be continued, passes into that of nausea, and if the pressure be increased, even excites vomiting. The feeling of nausea may be excited by mechanical irritation of any part of the surface of the fauces or soft palate; and this feeling is certainly much more allied to that of taste than to that of touch. Further, it has been observed by Henle, that if a small current of air be directed upon the tongue, it gives rise to a cool saline taste like that of saltpetre. Thus we find that the peculiar effects of

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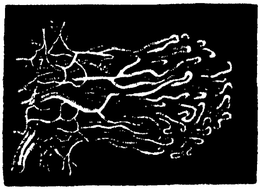
* For some pathological cases bearing upon the question of the implication of the chorda tympani in the sense of taste, see Inzani and Lussana, in the "Annali Universali di Med.," 1862, pp. 282-322; and Stich, in Henle and Meissner's "Bericht," 1857, p. 588. The two former observers believe the chorda tympani to be the true nerve of taste for the anterior part of the tongue, by which sweet, saline, piquant, and aromatic flavours are distinguished, whilst the mineral acids, astringents, bitters, pungent, putrefactive, and disgusting flavours are chiefly perceived through the glosso-pharyngeal. Schiff thinks the glosso-pharyngeal nerves are especially adapted to perceive bitter, and the Fifth nerves acid tastes. ("Physiologie," 1859, p. 403.)

† Translation of "Müller's Physiologie," p. 1062, *note*.

sapid substances upon the nerves of taste may be imitated to a certain extent by other agencies: and it also appears that the sensations excited by these vary according to the part of the gustative surface on which they operate; mechanical or electrical stimulation of the front of the tongue giving rise to a kind of saline taste, whilst mechanical stimulation applied to the back of the tongue and fauces excites the feelings of bitterness and nausea.—One of the conditions requisite for the due exercise of the gustative sense, is a temperature not departing far on either side from that which is natural to the body. It appears from the experiments of Prof. E. H. Weber,* that if the tongue be kept immersed for nearly a minute in water of about 125°, the taste of sugar brought in contact with it, either in powder or solution, is no longer perceived; the sense of touch, usually so delicate at the tip of the tongue, being also rendered imperfect. A similar imperfection of taste and touch was produced by immersing the tongue for the same length of time in a mixture of water and broken ice.

592. The surface of the Tongue is undoubtedly the special seat of gustative sensibility in Man; though the sense of Taste is not by any means restricted to that organ, being diffused in a less degree over the soft palate, the arches of the palate, and the fauces. It is on the tongue alone, however, that the papillary apparatus is fully developed; and its structure has been so carefully examined and described by Messrs. Todd and Bowman,† that little remains to be added to their account of it.—The lingual papillæ may be divided, in the first place, into the *Simple* and the *Compound;* the former of which had previously escaped observation, through not forming any apparent projection. The *Simple* papillæ are scattered in the intervals of the compound, over the general surface of the tongue; and they occupy much of the surface behind the circumvallate variety, where no compound papillæ exist. They are completely buried and concealed beneath the continuous sheet of epithelium, and can only be detected when this membrane has been removed by maceration; they are then found to have the general characters of the cutaneous papillæ. The *Compound* papillæ are visible to the naked eye; and have been classified, according to their shape, into the *circumvallate*, the *fungiform*, and the *filiform*. The *circumvallate* or calyciform papillæ are eight or ten in number, and are situated in a V-shaped line at the base of the tongue. Each consists of a central flattened circular projection of the mucous membrane, surrounded by a tumid ring of about the same elevation, from which it is separated by a narrow circular fissure. The surface of both centre and border is smooth, and is invested by scaly epithelium, which conceals a multitude of simple papillæ. The *fungiform* papillæ are scattered singly over the tongue, chiefly upon its sides and tip. They project considerably from the surface, and are usually narrower at their base than at their summit. They contain a complex capillary plexus (Fig. 126), the terminal loops of

Fig. 126.



Capillary plexus of *fungiform papilla* of the Tongue.

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* "Müller's Archiv," 1847, s. 342.

† "Physiological Anatomy and Physiology of Man," vol. i. chap. xv.

which enter the numerous simple papillæ that clothe the surface of the fungiform body. Amidst these lie nerve-tubes, which probably have a looped arrangement; and the epithelium which covers them is so thin, as to allow the red colour of the blood to be seen through it. In this manner they are readily distinguished from the filiform papillæ, among which they lie. The *filiform* papillæ, like the preceding, contain a plexus of capillaries and a bundle of nerve-fibres, both terminating in loops, which enter the simple papillæ that clothe the surface of the compound body; but instead of being covered with a thin scaly epithelium, they are furnished with bundles of long pointed processes, some of which approach hairs in their stiffness and structure. These are immersed in the mucus of the mouth, and may be moved in any direction, though they are generally inclined backwards.—The simple papillæ which occur in an isolated manner, may not improbably be tactile; whilst those which are aggregated in the circumvallate and fungiform bodies, doubtless minister to the sense of Taste, this being most acute in the situations wherein they most abound. With regard, however, to the office of the filiform papillæ, there seems much reason to coincide in the opinion of Messrs. Todd and Bowman:—"The comparative thickness of their protective covering, the stiffness and brush-like arrangement of their filamentary productions, their greater development in that portion of the dorsum of the tongue which is chiefly employed in the movements of mastication, all evince the subservience of these papillæ to the latter function, rather than to that of taste; and it is evident that their isolation and partial mobility on one another, must render the delicate touch with which they are endowed more available in directing the muscular actions of the organ. The almost manual dexterity of the organ, in dealing with minute particles of food, is probably provided-for, as far as sensibility conduces to it, in the structure and arrangement of these papillæ." It may be added, that the filiform papillæ of Man seem to be the rudimentary forms of those horny epithelial processes which acquire so great a development in the tongues of the Carnivora, and which are of such importance in the abrasion of their food. Some observers, as Billroth* and Stilling, think that in the frog the nerves of taste, especially in the fungiform papillæ, terminate in pencils of extremely fine fibrils, which join the delicate-pointed extremities of the conical non-ciliated epithelial cells covering the summit of those papillæ; whilst the ciliated epithelial cells situated on their sides, and elsewhere on the surface of the tongue, frequently run together at their bases into granular masses or sheets, which are continuous with the prolongations of the connective corpuscles, and through the intermediation of these with the fine, transparent, branched extremities of the subjacent muscular tissue-fibres. Axel Key† describes the nerve-fibres of the tongue in the same animal as being varicose, interrupted near their extremity by a cell, from which they are continued as rods reaching the surface in the intervals of the epithelial cells. Hoyer‡ and Hartmann,§ on the contrary, consider that these appearances are the result of manipulation; and that both the muscular and nervous fibres of the tongue terminate in free extremities, as was originally maintained by Waller* to be the case with the nerves of the tongue in Man, no fibres penetrating the limiting membrane of the papillæ, or forming connections with the investing epithelium.

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* 'On the Epithelial Cells of the Frog's Tongue,' "Müller's Archiv," 1858, p. 159.

† "Reichert's Archiv," 1861, p. 329.

‡ 'Microscopic Researches on the Tongue of the Frog,' "Reichert's Archiv," 1859, p. 481.

§ 'On the Mode of Termination of the Nerves in the Tongue of the Frog,' "Reichert's Archiv," 1863, p. 634.

593. The simple application of a sapid substance to the gustative surface is usually sufficient to excite the sensation; and if this application be restricted to one particular spot, we are able to recognize its place more or less distinctly. In this respect, then, the gustative impression resembles the tactile; for whilst we cannot, by our own consciousness, distinguish the parts of the retina or of the auditory apparatus on which visual or auditory impressions are made, we can make this distinction in regard to the surface which is supplied by the nerves of general sense. From the careful experiments of Stich and Klaatsch,† supported as they are by the results of other observations, we are now enabled to define with some accuracy the exact seats of the sense of taste. It exists over the whole surface of the posterior third of the dorsum of the tongue, on the under surface of the tip, and in a band or line, about one quarter of an inch broad, running along its edge. The sense is also well defined in the posterior part of the hard palate, and in that portion of the soft palate which is near the bone, and, lastly, in the anterior pillars of the fauces. The middle and anterior part of the dorsum, the gums, posterior pillars of the fauces, and the inner surface of the lips, possess no sense of taste. Bitters and acids appear to be the substances of which the dilution or attenuation may be carried to the greatest extent, without ceasing to excite sensations of taste, providing a sufficient volume of the solution be introduced into the mouth. Thus, according to Valentin, one part of extract of aloes or of sulphuric acid in 900,000 of water, and even one part of sulphate of quinine in 1,000,000 of water, may be distinguished if heedfully compared with perfectly pure water. The contact of a sapid substance much more readily excites a gustative sensation, when it is made to press upon the papillæ, or is moved over them. Thus there are some substances whose taste is not perceived when they are simply applied to the central part of the dorsum of the tongue, but of whose presence we are at once rendered cognizant by pressing the tongue against the roof of the mouth. The full flavour of a sapid substance, again, is more readily perceived when it is rubbed on any part of the tongue, than when it is simply brought in contact with it, or pressed against it. Even when liquids are received into the mouth, their taste is most completely discriminated by causing them to move over the gustative surface: thus the 'wine-taster' takes a small quantity of the liquor into his mouth, carries it rapidly over every part of its lining membrane, and then ejects it. It is not improbable that this exaltation of the usual effects is simply due to mechanical causes; the sapid particles being brought by the pressure or

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* The Author, in conjunction with Messrs. Bowman, T. Wharton Jones, and Kiernan, has most carefully examined the mode of termination of the nerves in the fungiform papillæ, with the view of testing the validity of the assertion of Dr. Waller ("Phil. Trans.," 1849) that they have free truncated extremities. No such terminations, however, could be exhibited to them by Dr. Waller.

† "Archiv f. Path. Anat.," band xiv., 1858, p. 225, and band xvii. p. 80.

movement into more rapid and complete operation on the nerve-fibres, than they would be if simply placed in contact with the papillæ.

594. The impressions made upon our consciousness by a large proportion of sapid substances are of a complex kind; being in part derived from their odorous emanations, of which we take cognizance through the organ of Smell. Of this any one may convince himself by closing the nostrils, and inspiring and expiring through the mouth only, whilst holding in the mouth, or even rubbing between the tongue and the palate, some aromatic substance; for its taste is then scarcely recognized, although it is immediately perceived when its effluvia are drawn into the nose. It is well known, too, that when the sensibility of the Schneiderian membrane is blunted by inflammation (as in an ordinary 'cold in the head'), the power of distinguishing flavours is very much diminished. In fact, some Physiologists are of opinion that *all* our knowledge of the *flavour* of sapid substances is received through the Smell; but this, as already shown, would not be a correct statement; and there are cases on record in which the sense of Smell has been entirely lost, without any impairment of the true sense of Taste.*

595. Taken in its ordinary composite acceptation, the sense of Taste has for its object to direct us in the choice of food, and to excite the flow of mucus and saliva, which are destined to aid in the preparation of the food for Digestion. Among the lower Animals, the instinctive perceptions connected with this sense are much more remarkable than our own; thus an omnivorous Monkey will seldom touch fruits of a poisonous character, although their taste may be agreeable; and animals whose diet is restricted to some one kind of food will decidedly reject all others. As a general rule it may be stated, that substances of which the taste is agreeable to us are useful in our nutrition, and *vice versâ*;† but there

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* An interesting case of this kind, occurring in a Negro who had gradually lost the characteristic hue of his skin, and had acquired the fair complexion of a European, has been put on record by Dr. J. C. Hutchinson.—The Olfactory nerve seemed to be entirely paralyzed, whilst the branches of the 5th Pair retained their integrity; so that, whilst the proper sense of Smell was entirely lost, a pungent burning sensation was excited by irritating vapours, and the application of snuff induced sneezing. Notwithstanding this deficiency, the sense of Taste, properly so called, did not seem to be impaired; for substances which possessed neither odour nor pungency could readily be discriminated, even though their tastes were not widely different. (See "Amer. Journ. of Med. Sci.," Jan. 1852.)

† It is justly remarked by Sir H. Holland ("Medical Notes and Reflections," p. 85), that,—"In the majority of instances of actual illness, provided the real feelings of the patient can be safely ascertained, his desires as to food and drink may be safely complied-with. But undoubtedly much care is needful that we be not deceived as to the state of the appetites, by what is merely habit or wrong impression on the part of the patient, or the effect of the solicitation of others. This class of sensations is more nurtured out of the course of nature, than are those which relate to the temperature of the body. The mind becomes much more deeply engaged with them; and though in acute illness they are generally submitted again to the natural law, there are many lesser cases where enough remains of the leaven of habit to render every precaution needful. With such precautions, however, which every physician who can take schooling from experience will employ, the stomach of the patient becomes a valuable guide; whether it dictate abstinence from a recurrence of food; whether much or little in quantity; whether what is solid or liquid; whether much drink or little; whether things warm or cold; whether sweet, acid, or saline; whether bland or stimulating to the taste." Further, Sir H. Holland remarks: "It is not wholly paradoxical to say that we are authorized to give greatest heed to the stomach, when it suggests some seeming

are many signal exceptions to this.—Like other senses, that of Taste is capable of being rendered more acute by education; and this on the principles already laid down in regard to Touch. The experienced wine-taster can distinguish differences in age, purity, place of growth, &c., between liquors that to ordinary judgments are alike; and the epicure can give an exact determination of the spices that are combined in a particular sauce, or of the manner in which the animal on whose flesh he is feeding was killed. As in the case of other senses, moreover, impressions made upon the sensory surface remain there for a certain period; and this period is for the most part longer than that which is required for the departure of the impressions made upon the eye, the ear, or the organ of smell. Every one knows how long the taste of some powerful substances remains in the mouth; and even of those which make less decided impressions, the sensations remain to such a degree that it is difficult to compare them at short intervals. Hence if a person be blindfolded, and be made to taste substances of distinct, but not widely-different flavours (such as various kinds of wine or of spirituous liquors), one after another in rapid succession, he soon loses the power of discriminating between them. In the same manner, the difficulty of administering very disagreeable medicines may be sometimes got-over, by either previously giving a powerful aromatic, or by combining the aromatic with the medicine; its strong impression in both cases preventing the unpleasant taste from exciting nausea.

4. *Sense of Smell.*

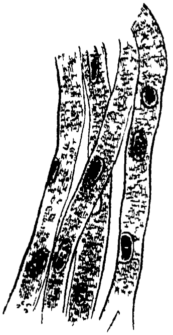
596. The Nasal passages may be considered as having, in air-breathing Vertebrata, two distinct offices; for they constitute the portal of the Respiratory organs, and have for their office to take cognizance of the aeriform matter as it enters them, and to give warning of that which would be injurious (this being effected by the instrumentality of the Fifth pair, which receives the impressions of gaseous irritants, and excites the act of sneezing to expel them; whilst they also contain the organ of Smell, which is formed by the distribution, over a certain part of their membranous wall, of the *Olfactory* nerve, which is susceptible of being impressed by Odorous emanations. Of the nature of these emanations the Physical Philosopher is so completely ignorant, that the Physiologist cannot be expected to give a definite account of the mode in which they produce sensory impressions. Although it may be surmised that they consist of particles of extreme minuteness, dissolved as it were in the air, and although this idea seems to derive confirmation from the fact that

extravagance of diet. It may be that this is a mere depravation of the sense of taste; but frequently it expresses an actual need of the stomach, either in aid of its own functions, or indirectly (under the mysterious law just referred-to) for the effecting of changes in the whole mass of blood. It is a good practical rule in such cases to withhold assent, till we find after a certain lapse of time that the same desire continues or strongly recurs; in which case it may generally be taken as the index of the fitness of the thing desired for the actual state of the organs. In the early stage of recovery from long gastric fevers, I recollect many curious instances of such contrariety to all rule being acquiesced-in, with manifest good to the patient. Dietetics must become a much more exact branch of knowledge, before we can be justified in opposing its maxims to the natural and repeated suggestions of the stomach, in the state either of health or disease."

most odorous substances are volatile, and *vice versâ*,—yet the most delicate experiments have failed to discover any diminution in weight, in certain substances (as musk) that have been impregnating a large quantity of air with their effluvia for several years; whilst there are some volatile fluids, such as water, which are entirely inodorous.

597. The Olfactory nerves pass-down from the Olfactory Ganglion in the form of very numerous minute threads, which form a plexus upon the surface of the Schneiderian or pituitary membrane (Fig. 129). The filaments composing this plexus are described by Messrs. Todd and Bowman* as differing widely in structure from those of the ordinary cephalic nerves; they contain no white substance of Schwann, are nucleated and finely-granular in texture, and altogether bear a close resemblance to the gelatinous form of nerve-fibres (Fig. 127). The mode in which these nerves terminate has recently been the subject of close investigation by Hoyer,† Schultze,‡ and Lockhart Clarke.§ Their distribution appears to be limited to the membrane covering the upper third of the septum of the nose, the superior turbinated bone, and perhaps the upper part of the middle turbinated bone; together with the upper wall of the nasal cavities beneath the cribriform plate of the ethmoid bone; all which surface is covered (as Messrs. Todd and Bowman have pointed-out) with an epithelium of a rich sepia-brown hue. According to Schultze these epithelial cells are divisible into two sets: one of these (*a*, Fig. 128) may be described as terminating externally by truncated flat surfaces which cannot be observed to be covered by any membrane separate from the contents of the cell. The contents themselves appear to consist of proto-plasma presenting a yellowish granular appearance in the outer part, whilst at the lower part an oval nucleus lying in clear protoplasm can be readily distinguished. Towards their attached extremity these cells become attenuated, and can be traced inwards for a considerable distance, when they expand into a broad flat sheet or plate, which, whilst it frequently presents a granular appearance, is never coloured. The processes which pass-off from this sheet appear to be continuous with the fibres of the submucous connective tissue. Towards the margin of the true olfactory region, cells (*c*, Fig. 128) in every respect analogous to those just described are found, excepting only that they present a well-defined band or seam at their free extremity, which is surmounted by a circle of cilia.—The cells of the second set (*b*, Fig. 128) have been described by Schultze as continuations of the nerves, and he has hence termed them 'Olfactory cells.' They are thin, fibrous- or rod-like bodies, terminating

FIG. 127.



Fibres of ultimate ramifications of *Olfactory Nerve* of Dog.

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* "Physiological Anatomy," vol. ii. p. 9.

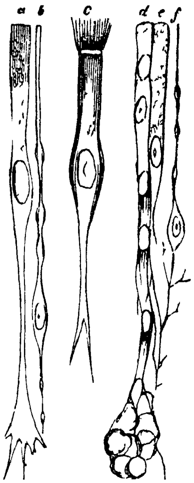
† Henle and Meissner's "Bericht," 1857, p. 27.

‡ "Untersuchungen über den Bau der Nasenschleimhaut," Halle, 4to.

§ "Zeits. f. Wissens. Zool.," band xi. For an abstract of this paper, see "Med.-Chir. Review" for 1862, vol. i. p. 521.

at the same level as the proper epithelial cells, and presenting when traced inwards a series of moniliform or varicose swellings which are directly continuous with outrunners of more deeply-seated nerve-cells. Closely analogous appearances have been seen and described by Lockhart Clarke, who states that the Olfactory Nerve-fibres on reaching the base of the epithelial layer divide into finer and still finer branches, to form a network with numerous interspersed nuclei, through which they are probably connected with the "Olfactory cells" (*f*, Fig. 128), although he has never been able satisfactorily to convince himself of such connection. The proper epithelial cylinders (*d*, *e*) are connected at their bases with the septa formed of connective tissue belonging to the subepithelial glandular layer.—The remainder of the nasal surface is supplied by the Fifth pair only, and is not endowed with sensibility to odours, although it is susceptible of irritation from such as are of a pungent nature; and hence it is that we cannot distinguish faint odours, unless, by a peculiar inspiratory effort, we draw the air charged with them to the upper part of the nose. In animals living in the air, it is a necessary condition of the exercise of the sense of Smell, that the odorous matter should be transmitted by a respiratory current through the nostrils, and that the membrane lining these should be in a moist state. Hence, by breathing through the mouth, we may avoid being affected by odours even of the strongest and most disagreeable kind; and in the first state of a catarrh, when the ordinary mucous secretion is suspended, the sense of Smell is blunted from this cause, as it afterwards is from the excess in the quantity of the fluid, which prevents the odoriferous effluvia from coming into immediate relation with the sensory extremities of the nerves. Hence we may easily comprehend how section of the Fifth Pair, which exerts a considerable influence over the secretions, will greatly diminish the acuteness of this sense, and will have the further effect of preventing the reception of any impressions of irritation from acrid vapours, which are entirely different in their character from true odorous impressions, and are not transmitted through the Olfactory nerve (§ 503).

FIG. 128.

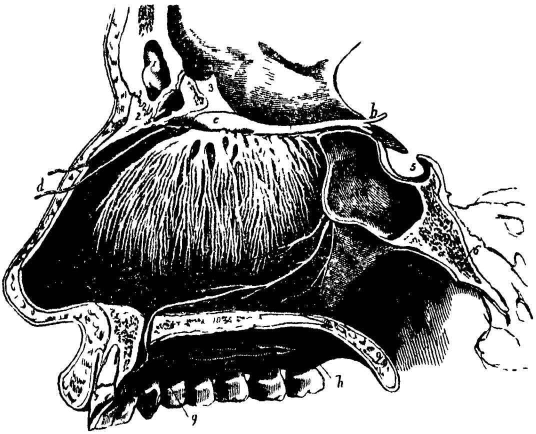


Cells of the Olfactory Mucous Membrane —*a*, *b*, *c* after Schultze; *d*, *e*, *f* after Lockhart Clarke.

598. The importance of the sense of Smell among many of the lower Animals, in guiding them to their food, or in giving them warning of danger, and also in exciting the sexual feelings, is well known. To Man its utility is comparatively small under ordinary circumstances; but it may be greatly increased when other senses are deficient. Thus, in the well-known case of James Mitchell, who was blind, deaf, and dumb, from his birth, it was the principal means of distinguishing persons, and enabled him at once to perceive the entrance of a stranger. It is recorded that a blind gentleman, who had an antipathy to cats, was possessed of a sensibility so acute in this respect, that he perceived the proximity of one that had been accidentally shut-up in a closet adjoining his room. Among

Savage tribes, whose senses are more cultivated than those of civilized nations, more direct use being made of the powers of observation, the scent is almost as acute as in the lower Mammalia: thus it is asserted by Humboldt, that the Peruvian Indians in the middle of the night can distinguish the different races, whether European, American-Indian, or Negro; and the Arabs of the Great Desert are said to be able to distinguish the smell of a fire thirty miles off.—The quantity of some odorous bodies which is capable of exciting a distinct perception of Smell, must in some instances be exceedingly small. A very minute trace of sulphuretted hydrogen is readily recognized, and according to Valentin, one part of bromine in 200,000 of air communicates an unpleasant odour to the latter, whilst in the case of musk a proportion not greater than one part in 13,000,000 of air is still perceptible.—The agreeable or disagreeable character assigned to particular odours, is by no means constant amongst different individuals. Just as many of the lower animals pass their whole lives in the midst of odours that are to Man (in his civilized condition at least) in the highest degree revolting, and will even refuse to touch food until it is far advanced in putridity, so do we find that men who are compelled by circumstances to live upon putrescent food, come at last to relish it most when it is furthest advanced in decomposition (§ 51); and the most refined epicures among highly-civilized communities seem to find pleasure in similar odours and savours, which to ordinary

FIG. 129.



Distribution of the *Olfactory Nerve* on the Septum Nasi. The nares have been divided by a longitudinal section made immediately to the left of the septum, the right nares being preserved entire.—1. The frontal sinus. 2. The nasal bone. 3. The crista galli process of the ethmoid bone. 4. The sphenoidal sinus of the left side. 5. The sella turcica. 6. The basilar process of the sphenoidal and occipital bones. 7. The posterior opening of the right nares. 8. The opening of the Eustachian tube in the upper part of the pharynx. 9. The soft palate, divided through its middle. 10. Cut surface of the hard palate. *a.* The olfactory peduncle. *b.* Its three roots of origin. *c.* Olfactory ganglion, from which the filaments proceed that spread-out in the substance of the pituitary membrane. *d.* The nasal nerve, a branch of the ophthalmic nerve, descending into the left nares from the anterior foramen of the cribriform plate, and dividing into its external and internal branch. *e.* The naso-palatine nerve, a branch of the spheno-palatine ganglion, distributing twigs to the mucous membrane of the septum nasi in its course to (*f*) the anterior palatine foramen, where it forms a small gangliform swelling (Cloquet's ganglion) by its union with its fellow of the opposite side. *g.* Branches of the naso-palatine nerve to the palate. *h.* Posterior palatine nerves. *i, i.* The septum nasi.

tastes are anything but agreeable.—As to the length of time during which impressions made upon the organ of Smell remain upon it, no certain knowledge can be obtained. It is difficult to say when the effluvia themselves have been completely removed from the nasal passages, since it is not unlikely that the odorous particles (supposing such to exist) are absorbed or dissolved by the mucous secretion; it is probably in this manner that we may account for the fact, well known to every medical man, that the cadaverous odour is frequently experienced for many days after a post-mortem examination.*

5. *Sense of Vision.*

599. The objects of this sense are bodies from which Light proceeds, either because they are luminous in themselves, or because they reflect the light that proceeds from other bodies. Whether their light is transmitted by the actual *emission* of luminous particles, or by the propagation of *undulations* analogous to those of sound, is a question that has been long keenly debated amongst Natural Philosophers; but it is of little consequence to the Physiologist *which* is the true solution, since he is only concerned with the laws according to which the transmission takes place, which are the same on both theories. These laws it may be desirable here briefly to recapitulate.

600. Every point of a luminous body sends-off a number of rays, which diverge in every direction, so as to form (as it were) a cone, of which the luminous point is the apex. So long as these rays pass through a medium of the same density, they proceed in straight lines; but if they enter a medium of different density, they are *refracted* or bent,—*towards* the perpendicular to the surface at the point at which they enter, if they pass from a rarer into a denser medium,—and *from* the perpendicular, when they pass from a denser medium into a rarer. It is easily shown to be a result of this law, that, when parallel rays passing through air fall upon a convex surface of glass, they will be made to converge; so as to meet at the opposite extremity of the diameter of the circle, of which the curve forms part. If, instead of continuing in the glass, they pass-out again, through a second convex surface, of which the direction is the reverse of the first, they will be made to converge still more, so as to meet in the centre of curvature. Rays which are not parallel, but which are diverging from a focus, are likewise made to converge to a point or focus; but this point will be more distant from the lens, in proportion as the object is nearer to it, and the angle of divergence consequently greater. The rays diverging from the several points of a luminous object, are thus brought to corresponding foci; and the places of all these foci hold exactly the same relation to each other, with that of the points from which the rays diverged; so that a perfect image of the object is formed upon a screen held in the focus of the lens. This image, however, will be inverted; and its size, in proportion to that of the object, will depend upon their respective distances from the lens. If their distances be the same, their size will also be the same; if the object be distant, and the image near, the latter will be much the smaller: and *vice versâ*.

601. There are two circumstances, however, which interfere with the

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* This may partly be attributed also to the effluvia adhering to the dress. It has been remarked that *dark* cloths retain these more strongly than *light*.

perfection of an image thus formed by a convex lens. The one is, that, if the lens constitute a large part of the sphere from which it is taken, the rays which fall near its margin are not brought to a focus at the same point with those which pass through its centre, but at a point nearer the lens. This difference, which must obviously interfere greatly with the distinctness of the image, is termed *Spherical Aberration ;* it may be corrected by the combination of two or more lenses, of which the curvatures are calculated to balance one another, in such a manner that all the rays shall be brought to the same focus; or by diminishing the aperture of the lens by means of a stop or diaphragm, in such a manner that only the central part of it shall be used. The latter of these methods is the one employed, where the diminution in the amount of light transmitted is not attended with inconvenience. The nearer the object is to the lens (and the greater, therefore, the angle of divergence of its rays), the greater will be the spherical aberration, and the more must the aperture of the diaphragm be reduced in order to counteract it. The term astigmatism* (α, privative, and στιγμα, a point) has been applied by Professor Whewell to a condition of the eye (first observed in himself by Professor Airy) in which there is an inequality in the refractive power (owing to difference in the degree of curvature either of the cornea, or of the lens, or of both) between the horizontal and vertical meridians of the eye. There is a consequent incapacity on the part of the eye to collect all the rays of light entering it to one exact focus; this has been shown by Donders to be of common occurrence in those who are otherwise healthy. In such persons there are two foci, one for horizontal and the other for vertical rays. This condition may be remedied by the use of the so-called cylindrical glasses.—The other circumstance that interferes with the distinctness of the image, is the unequal refrangibility of the differently-coloured rays which together make-up white or colourless light; the violet being more bent from their course than the blue, the blue more than the yellow, and the yellow more than the red; the consequence of which will be, that the violet rays are brought to a focus much nearer to the lens than the blue, and the blue nearer than the red. If a screen be held to receive the image in the focus of any of the rays, the others will make themselves apparent as fringes round its margin. This difference is termed *Chromatic Aberration.* It is corrected in practice, by combining together lenses of different substances, of which the *dispersive* power (that is, the power of separating the coloured rays) differs considerably. This is the case with flint and crown-glass, for instance,—the dispersive power of the former being much greater than that of the latter, whilst its refractive power is nearly the same; so that, if a convex lens of crown-glass be united with a concave of flint whose curvature is much less, the dispersion of the rays effected by the former will be entirely counteracted by the latter, which diminishes in part only its refractive power.†

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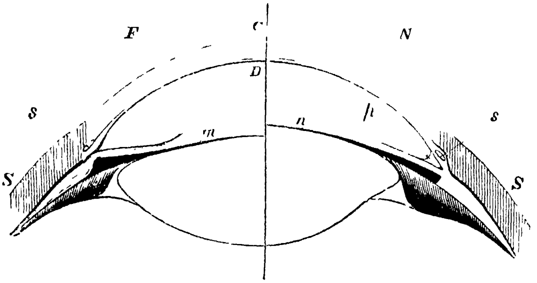
* See Donders' "Astigmatismus," &c. (Berlin, 1862); the "Oration" delivered by Mr. Z. Laurence before the North London Medical Society, 1863, and his papers in the "Med. Times and Gazette" for 1862-63; also Mr. Wharton Jones's abstract of paper read before the Royal Society, in "Proceedings of the Royal Society" for 1859, vol. x. p. 374.

† For an able summary of the most recent researches on the optical relations of the Eye, see "Med.-Chir. Review," January, 1862. See also the papers of Mr. J. S. Wells, in the "Royal London Ophthalmic Hospital Reports," vols. ii. and iii.

602. The Eye may be regarded as an optical instrument of great perfection, adapted to produce, on the surface of the Retina, a complete image or picture of luminous objects brought before it; in which the forms, colours, lights and shades, &c. of the object are all accurately represented. By the different refractive powers of the transparent media through which the rays of light pass, and by the curvatures given to their respective surfaces, both the Spherical and Chromatic aberrations are corrected in a degree sufficient for all practical purposes; so that, in a well-formed eye, the picture is quite free from haziness and from false colours. The power by which it adapts itself to variations in the distance of the object,—so as to form a distinct image of it, whether it be six inches, six yards, or six miles off,—is extremely remarkable, and cannot be regarded as hitherto completely explained. It is obvious that, if we fix upon any distance as that for which the eye is naturally adjusted (say 12 or 14 inches, the distance at which we ordinarily read), the rays proceeding from an object placed nearer to the eye than this would not be brought to a focus upon the retina, but would converge towards a point behind it; whilst, on the contrary, the rays from an object at a greater distance would meet before they reach the retina, and would have again diverged from each other when they impinge upon it; so that, in either case, vision would be indistinct. Now, two methods of adaptation suggest themselves to the Optician. Either he may vary the distance between the refracting surface and the screen on which the image is formed, in such a manner that the latter shall always be in the focus of the converging rays; or, the distance of the screen remaining the same, he may vary the convexity of his lens, in such a manner as to adapt it to the distance of the object. The mode in which this adaptation is effected in the Human Eye has been carefully investigated by Czermak, Helmholtz, and others. According to the calculations of Olbers, based on the ascertained refractive powers of the media of the eye, the difference between the focal distances of the images of two objects, the one so far off that its rays are parallel, and the other at the distance of only four inches from the eye, is about 0·143, or one-seventh of an inch; but as the usual range of distinct vision does not extend to objects brought within six or seven inches, the amount of change required in the relative places of the refracting bodies and the retina would not ordinarily exceed a line. It has been thought that this change might be produced by an alteration in the convexity of the cornea, or by an elongation of the globe of the eye generally, or by both methods in combination; but a strong counter-argument to these opinions is derived from a case which came under the observation of v. Grafe, in which the power of accommodation was preserved, although from paralysis of the Third Nerve all the ocular muscles were paralyzed, except the external rectus and the superior oblique. There is much more ground for the belief that a change of form and perhaps of place is effected in the crystalline lens, by the action of the ciliary muscle and the erectile tissue of the ciliary processes; for not only can it be shown that the contraction of the ciliary muscle would tend to compress the lens, but the fact that this muscle is peculiarly powerful in the predaceous Birds, which are distinguished for their great range of vision, and which have, in their circle of osseous sclerotic plates, an unusually firm point of attachment for it, is a strong argument

in favour of this doctrine.* Further, the almost entire loss of the power of adapting the eye to distances, which is experienced after the removal of the Crystalline lens in the operation for Cataract, is a marked indication that some change in the place or figure of this body is the principal means whereby the ordinary adaptation is effected. The precise changes which occur in the interior of the Eye when it is accommodated for viewing near objects, or during *positive accommodation*, have been determined by Helmholtz† with an instrument that he has termed an Ophthalmometer, the principle of which consists in examining the reflection from the various ocular media of two flames:—alterations in the relative position and figure of these can be readily perceived and measured, furnishing the data for the requisite calculations. By this means it has been ascertained that the essential alteration is a change effected by muscular effort in the figure of the lens, which increases in thickness in its antero-posterior diameter, the convexity of the anterior surface in particular undergoing a considerable augmentation (*n*, Fig. 130), and by a forward movement approximating the cornea; whilst the convexity of the posterior surface is but slightly modified, and undergoes scarcely any change of place. The return of the lens to its original figure after the cessation of the effort by which it has been accommodated for near objects is probably effected by its own elasticity, which is certainly very considerable. The other and clearly secondary changes which have been observed are a contraction of the circular fibres of the Iris, making the pupil smaller—the pupillary edge of the Iris at the same time moving forwards, and the attached or peripheral edge (*p*) backward. The forward movement of the plane of the iris amounts, according to Knapp,‡ to about 1-12th of an inch: Czermak was, however, unable to perceive any arching forward of the iris, and

Fig. 130.



C, Cornea; S, Sclerotic; F C N, Vertical plane of the Cornea; B C D, Axis of the Eye; *s s*, Canal of Schlemm; *p*, Angle formed by the Iris and Cornea, or margin of anterior Chamber; *m*, Position of Iris, and curvature of Lens in an Eye converged for parallel rays, distant vision, or negative accommodation; *n*, Position of Iris, and curvature of lens required for near objects, or for positive accommodation.

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* See on this subject, Messrs. Todd and Bowman's "Physiological Anatomy," vol. ii. p. 27; and Dr. Clay Wallace on "The Adjustment of the Eye to Distances," New York, 1851.

† A full confirmation of Helmholtz's statements, with a good historical *resumé* of the whole subject, will be found in Prof. Allen Thomson's "Phenomena and Mechanism of the Focal Adjustment of the Eye to Distinct Vision at Different Distances" (pamphlet).

‡ "Archiv f. Ophthalmol.," band vi. abtheil. ii. p. 1.

believes that its plane remains perpendicular. Lastly, according to Becker,* the points of the ciliary processes retire from the edge of the lens. That the presence of the Iris is not indispensable for the performance of positive accommodation, is shown by the fact that, in a patient from whom Grafe removed the whole Iris, this faculty remained perfect; and a similar power has been observed to exist in cases of congenital absence of the Iris.†—The object fulfilled by the contraction of the pupil in adaptation of the Eye for near objects, is evidently to exclude the outer rays of the cone or pencil, which, from the large angle of their divergence, would fall so obliquely on the convex surface of the eye as to be much affected by the spherical aberration, and thus to allow the central rays only to enter the eye, so as to preserve the clearness of the image; the principle being exactly the same as that on which the optician applies a *stop* behind his lenses, which reduces their aperture in proportion to the shortness of their focal distance. The channel through which this action is effected, is evidently the same as that through which the convergence of the eyes is produced,—namely, the inferior branch of the Third pair of nerves; to the action of which, the sensations received through the retina seem to afford the immediate stimulus, in the same manner as they do to the ordinary variation in the diameter of the pupil under the influence of light; but the voluntary determination to fix the vision upon the object, is the original source of the action. During *negative accommodation*,—in other words, in viewing distant objects,—the lens (*m*) becomes flattened, the external margin of the iris is brought forward, the pupil dilates, and the tips of the ciliary processes are approximated to the margin of the lens. The main instrument in effecting these changes in the Eye appears to be the *Ciliary Muscle*, the structure and attachments of which were first clearly described by Mr. Bowman. It consists of unstriped muscular fibre, partly arranged in a circular manner, the innermost fibres running parallel to the margin of the Cornea, and partly disposed radially, the fibres of the latter portion of the muscle appearing to be connected at their origin with the posterior elastic lamina of the Cornea, and externally or posteriorly being partly inserted into the Iris, forming the pillars of the Iris (Ligamentum pectinatum iridis), partly into the Sclerotic bounding the canal of Schlemm (*s*, Fig. 130), and partly into that part of the outer surface of the choroid tunic, which corresponds to the ciliary processes. The mode and effects of the contraction of this muscle have not been determined with perfect certainty; some, as Brucke, believing the anterior attachment to be the origin, or fixed point, towards which in contraction the posterior extremity is drawn; others, as Donders, that the posterior border is the true origin; and others again, as Helmholtz, considering that both extremities are moveable. According to Cramer, Donders, H. Muller, and others, the lens, when adapted for viewing infinitely-distant objects, is at rest, and it is only when near objects are looked at that a change is impressed on the figure and position of the lens; Cramer attributing this effect especially to pressure exerted by the iris, and H. Muller to the ciliary muscle. Helmholtz, Arlt, and Jäger, on the contrary, consider that the lens is flattened in viewing distant objects, through the traction exerted by an elastic membranous zonula attached to its edge. When the ciliary muscle contracts, which occurs in viewing near objects, the posterior border of the zonula is drawn forward, and its tension, and therefore the flattening power it exerts upon the lens, is diminished. A third supposition has been advanced by Henke and Langenbeck* to the effect that a muscular effort is required in arranging the Eye for viewing both near and distant objects, the former being accomplished through the contraction of the circular fibres, the latter through that of the radial fibres;† but a strong argument against this view is derived from the circumstance that no fatigue is experienced from prolonged direction of the Eye to *distant* objects, whilst the employment of the visual power upon near objects for some time is accompanied with a sense of effort, and is followed by fatigue. The movement which effects the change of form of the crystalline lens, is performed in obedience to Volition, and is guided by sensation; yet we are not conscious of performing it, all that we *will* being the *result;* and thus we have another apposite illustration of the really automatic nature of what are termed 'voluntary movements' generally (§ 531). The time occupied in accommodating the Eye for near objects is greater than that required for adapting it to view distant objects. According to Aby the period occupied in changing the accommodation from 17 to $4\frac{1}{2}$ inches is about 2 seconds, whilst in changing it from $4\frac{1}{2}$ to 17 inches only 1·2 seconds are required. Vierordt, however,‡ states that he was able to effect the accommodation from 60 feet to $4\frac{1}{2}$ inches in about nine-tenths of a second, and from $4\frac{1}{2}$ inches to 60 feet in about seven-tenths of a second. Differences in age, and in amount of practice, are probably the chief causes of such variations in the results of different observers; accommodation for near objects being always accomplished more slowly with the advance of years.—In healthy, or as Donders terms them, 'emmetropic' eyes, the limits of clear vision lie between two points, the 'near-point' and the 'far-point.' The former, very near the eye in infancy, gradually recedes with advancing age; and Fellenberg§ has shown, that at 10 years of age it is $2\frac{2}{3}$ inches distant from the front of the cornea; at 20 years of age, $3\frac{5}{9}$ in.; at 30, $4\frac{4}{5}$ in.; at 40, $6\frac{6}{7}$ in.; at 50, 12 in.; at 60, 24 in.; and at 70, 144 inches. The 'far-point' for healthy eyes is infinite distance, or in other words, the refractive media of healthy eyes in a condition of repose are adapted to bring parallel rays to a focus on the retina. The extent of the range of vision for each eye is very considerable, amounting, according to Korn and Forster,‖ in the horizontal direction, to an arc of 130°, and in the vertical to an arc of 116°.

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* See his interesting paper in Braun, Duchek, and Schlager's "Medizin. Jahrb." 1864, p. 1.

† See Dr. Soelberg Wells' instructive paper 'On the Paralysis of the Muscles of the Eye,' in the "Ophthalmic Hospital Reports," vol. ii. 1859-1860, p. 199.

603. When both eyes are fixed upon an object, their axes converge so as to meet in it; and the degree of convergence is of course altered by variations in the distance of the object; since, when the object is very remote, the optic axes are virtually parallel, whilst its approach causes them to incline towards each other, and this the more rapidly as the object is brought nearer, the increase being the greatest when it has

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* Henle and Meissner's "Bericht," 1860, p. 561.

† An opinion to which Gräfe seems also to have been led from a comparison of the effects of belladonna and opium upon the iris and upon the ciliary muscle (as indicated by the power of accommodation) respectively.

‡ Henle and Meissner's "Bericht," 1857, p. 547.

§ Canstatt's "Jahresbericht" for 1862, p. 157.

‖ Ibid.

arrived within the ordinary distance of distinct vision. Here, again, we have an example of the automatic nature of voluntary actions; for the convergence of the eyes that may be produced by this gradual approximation of an object on which the eyes are kept-fixed by an exercise of the Will, far exceeds that which most individuals can induce by an effort made directly for the purpose; and if, when an object has thus been gradually approximated to within a few inches of the nose, the voluntary fixation be intermitted, and the optic axes be allowed to regain their parallelism, they can seldom be brought to converge again upon it, without repeating the whole process.—It has been thought, from the close accordance between the changes required for the adaptation of the eyes to distinct vision at different distances, and the alterations in the direction of the optic axes which are required to bring the two eyes to bear upon objects at varying degrees of proximity or remoteness, that the former of these movements is in some degree dependent upon the latter, or, at any rate, that the two proceed from a common motor impulse. But that the convergence of the axes is not itself in any way the occasion of the alteration of the focus of the eye, is shown by these two facts; first, that the adaptation is as perfect in a person who only possesses or uses one eye, as it is when both are employed; and second, that some persons possess the power of altering the focus of the eyes by an effort of the will, whilst the convergence remains the same.

604. The ordinary forms of defective vision, which are known under the names of *Myopia* and *Presbyopia*, or 'short-sightedness' and 'long-sightedness,' are entirely attributable to defects in the optical adaptation of the eye. In the former, its refractive power is too great; the rays from objects at the usual distance are consequently brought too soon to a focus, so as to cross one another and diverge before they fall upon the retina; whilst the eye is adapted to bring to their proper focus on the retina, only those rays which were previously diverging at a large angle, from an object in its near proximity. Hence a 'short-sighted' person, whose nearest limit of distinct vision is not above half that of a person of ordinary sight, can see minute objects more clearly; his eyes having, in fact, the same magnifying power which those of the other would possess, if aided by a convex glass that would enable him to see the object distinctly at the shortest distance. But as the myopic structure of the eye materially diminishes the distance of his far-point, and incapacitates its possessor from seeing objects clearly at even a moderate distance, it is desirable to apply a correction; and this is done by simply interposing between the object and the eye a *concave* lens, of which the curvature is properly adapted to compensate for the excess of that of the organ itself.—On the other hand, in the presbyopic, or, as designated by Donders, the hypermetropic eye,* the curvature and refractive power are not sufficient

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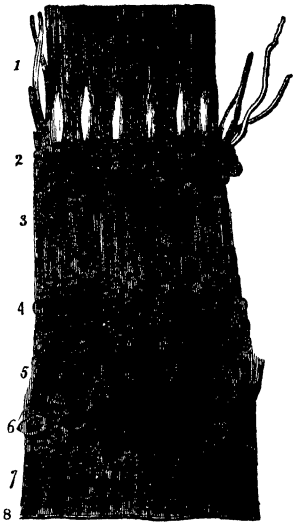
* The term Presbyopia is limited by Donders to the condition in which, as the result of the increase of years, the range of accommodation is diminished, and the vision of near objects is interfered with. Myopia and Presbyopia are, therefore, by no means opposite conditions; they may even co-exist, as in an eye which can only see accurately from 20" to 14"; for here the farthest point of distinct vision is situated at too short a distance (Myopia); the nearest point at too great a distance (true Presbyopia). The real opposite to Myopia is Hypermetropia, in which the principal focus falls behind the retina, as in Myopia it falls in front of the retina.—See Donders' treatise on "Accommodation and Refraction of the Eye;" New Syd. Soc. Trans., 1864, pp. 84 and 210.

to bring to a focus, on the retina, rays which were previously divergent in a considerable or even in a moderate degree; and indistinct vision in regard to all near objects is, therefore, a necessary consequence, whilst distant objects are well seen. This defect is remedied by the use of *convex* lenses, which make-up for the deficiency of the curvature. The term 'presbyopia,' as limited by Donders, simply expresses a deficient power of accommodation in the eye, resulting from increased density of the lens, or from paralysis of the ciliary muscle, so that the 'near-point' recedes beyond a certain point, arbitrarily fixed by Donders for the sake of convenience at eight inches.—The effects of Atropine upon the Eye are very remarkable, not only in dilating the pupil to the utmost, but in completely paralyzing the power of accommodation, so that the 'near-point' becomes gradually more and more distant, till at length it coincides with the 'far-point.' The Calabar bean, on the contrary, causes extreme contraction of the pupil, the 'far-point,' and in many eyes the 'near-point' also, becoming approximated to the eye, though the power of accommodation is never altogether lost.—We commonly meet with myopia in young persons, and with presbyopia in old; but this is by no means the invariable rule; for even aged persons are sometimes 'short-sighted,' and 'long-sightedness' is occasionally met-with amongst the young. In choosing spectacles for the purpose of correcting the errors of the eye, it is of great consequence not to make an over-compensation; for this has a tendency to increase the defect, besides occasioning great fatigue in the employment of the sight. It may be easily found when a glass of the right power has been selected, by inquiring of the individual whether it alters the apparent size of the objects, or only renders them distinct. If it alter the size (increasing it, if it be a convex lens, and diminishing it, if it be a concave), its curvature is too great; whilst if it do not disperse the haze, it is not sufficiently powerful. In general it is better to employ a glass which somewhat under-compensates the eye, than one whose curvature is at all too high; since, with the advance of years in elderly persons, a progressive increase in power is required; whilst, as young persons grow-up to adult age, they should endeavour to dispense with the aid of spectacles.—Many other interesting inquiries, respecting the action of the Eye as an optical instrument, suggest themselves to the Physical philosopher; but the foregoing are the chief in which the Physiologist is concerned; and we shall now proceed, therefore, to consider the share which the Nervous apparatus performs in the phenomena of vision.

605. The Optic Nerve, at its entrance into the eye, divides itself into numerous small fasciculi of ultimate fibrils; and these appear to spread themselves out, and to inosculate with each other by an exchange of fibrils, so as to form a net-like plexus, which constitutes the inner layer of the Retina (Fig. 131, 7) in immediate contact with the 'limitary membrane' (8). There is considerable difficulty, however, in the precise determination of the course of the nerve-fibres in the Retina, on account of their minute size and the alteration in their characters. Although uniformly much smaller than ordinary nerve-fibres, they present considerable diversities in size (Fig. 132, 1, 2); the largest of them being only about 1-6000th of an inch in diameter, whilst the smallest are no more than from 1-30,000th to 1-50,000th of an inch. Notwithstanding the statement of Prof. Kölliker, that they closely resemble the finest nerve-tubes in the central organs, he has not been able to demonstrate their

tubular character; and it is considered by Mr. Bowman that, like the fibres of the Olfactive tract (§ 597), they consist of axis-cylinders without sheaths. Perhaps the fact may rather be, that they are in that early stage of development, in which the components of a complete tubular fibre have not yet been differentiated.—Externally to the stratum of nerve-fibres, which may be called the Optic layer, is a vesicular stratum (Fig. 131, 6), which consists of a finely-granular matrix, wherein are imbedded nerve-cells exactly resembling those of the Encephalon, and having, like them, a variable number of processes, some of which appear to become continuous with the fibres about to be described. It is to these fibrous and vesicular layers of the Retina, which together make-up the analogue of the cortical substance of the Cerebrum, that the principal supply of blood is distributed, by the minute capillary network (Fig. 133), which is spread-out through their substance.—The principal part of the thickness of the Retina, however, is made-up of a series of layers whose structure has until lately been completely misunderstood; and though their real character cannot be regarded as yet fully elucidated, yet a great step has been made in advance by the researches of H. Muller and Kolliker.* These layers, as seen in a vertical section (Fig. 131), succeed each other from within outwards as follows:—In contact with the vesicular layer (6) is a layer of finely-granular matter of a greyish hue, in which an indistinct radiating fibrous appearance is seen; next is a layer of definite granules (4), which seem like minute cells closely investing nuclei; outside this is another layer (3), in which the appearance of radiating fibres is more distinct; this, again, is succeeded by another granular layer (2) resembling the preceding; and outside all these is the layer (1) of 'cones' and 'rod-like' bodies, which has long been known as 'Jacob's membrane.' This last has been supposed to be entirely disconnected, both structurally and functionally, from the proper nervous apparatus of the Retina; but recent investigations have made it probable that it really forms part of it. For the 'rods' or 'staff-like' bodies (Fig. 132, *a a*), may

FIG. 131.



Vertical Section of *Retina* of the Human Eye:—1, bacillar layer; 2, outer granular layer; 3, intermediate fibrous layer; 4, inner granular layer; 5, finely-granular grey layer; 6, layer of nerve-cells; 7, layer of fibres of optic nerve; 8, limitary membrane.

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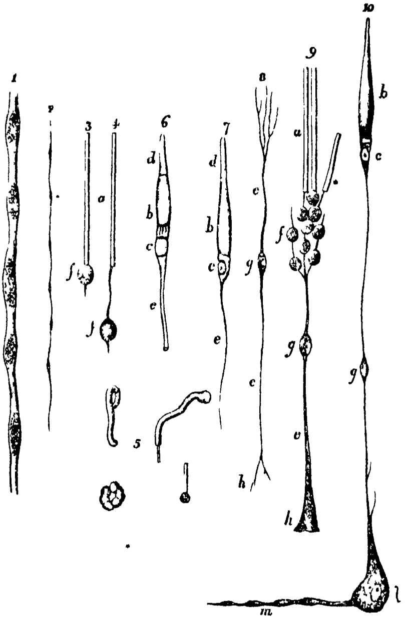
* See the Memoir of the former, 'Zur Histologie der Netzhaut,' in Kölliker and Siebold's "Zeitschrift," 1851; and the "Mikroskopische Anatomie," band ii. § 274, and the "Manual of Human Histology" (Sydenham Society's Ed.), vol. ii. pp. 368–382, of the latter. See also Mr. Bowman's "Lectures on the Parts concerned in the Operations on the Eye," p. 81, and Todd and Bowman's "Physiological Anatomy," vol. ii. pp. 28–30. Nunneley "On the Organs of Vision" (London, 1858) contains a good account of the Eye, and many very carefully-taken measurements. See also Krause in "Zeits. f. Rat. Med.," band xi.; H. Müller in "Würzburg Naturwissens. Zeitschrift," band ii.

be traced into continuity with the granules (*f*, *f*) of the outer granular layer, sometimes immediately, sometimes by the intervention of a fine fibrous prolongation; and from the granules of the outer layer, fine fibres (*e*, *e*) may be traced towards those of the inner layer (*g*, *g*). So, again, the 'cones' (*b*, *b*), whose outer extremities (*d*, *d*) are often seen on the external surface as 'rods,' may be traced into continuity with the granular layers (*f*, *g*,) by the intermediation of fine fibres (*e*, *e*). And from the outer granular layer, similar very delicate fibres are found to pass towards the vesicular layer, where some of them appear to come into absolute continuity with the radiating prolongations of the nerve-cells (10, *l*), whilst others pass through the vesicular layer, and expand into trumpet-shaped terminations (9, *h*), in the stratum of optic fibres. The effects of reagents, moreover, on these elements, are such as to increase this probability. It is to be remarked especially of the rod-like bodies, that they are very speedily and remarkably altered by the contact of water, which causes them to undergo contortions and irregular bulgings and contractions (5).—Although the general direction of the fibrous elements of the Retina itself (as distinguished from those of the Optic Nerve) is *radial* as regards the globe of the eye, or *vertical* as regards any part of the surface of the membrane, yet there are situations in which the rod-like bodies are directed so obliquely, as to present quite an imbricated arrangement upon the external surface (Fig. 134).

FIG. 132.

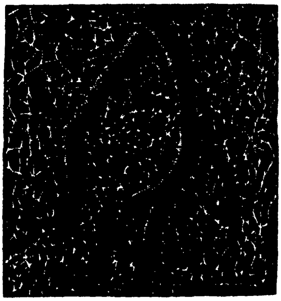


Elements of *Human Retina*:—1, large fibre of optic nerve; 2, very fine fibre of the same; 3, rod with a granule *f* attached; 4, a similar rod with a fine fibrous prolongation, connecting it with the granule; 5, portions of rods altered by the action of water; 6, 7, two cones *b b*, with their nuclei *c c*, their bacillar portions *d d*, and their fine fibrous prolongations *e e*; 8, radiating fibre *e e*, with granule of outer layer *g*, and subdividing in the bacillar layer, as well as in the optic layer *h*; 9, connection of rods *a*, with granules of inner layer *f*, granule of outer layer *g*, and expansion of the fibre proceeding from the latter in the optic layer at *h*; 10, similar connection of cone *b c*, with granule *g*, and with nerve-cell *l*, which has another fibrous prolongation *m*.

606. There are two spots in the Retina, in which the arrangement of the foregoing components is essentially different; and from these differences, important physiological conclusions may be drawn. One of these is the slight eminence at which the Optic nerve enters, which is a little below and internal-to the posterior extremity of the axis of the eye; here all the other elements than the nerve-fibres are entirely wanting. The other is the 'yellow spot of Soemmering,' which is

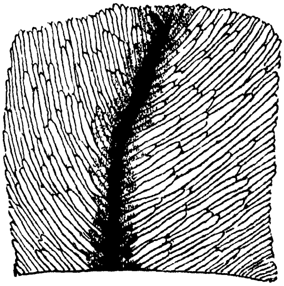
situated in the exact centre of the retina; here the stratum of optic fibres is wanting, the nerve-cells being in immediate contact with the limitary membrane; the granular layer is deficient in the centre, so that the pigment of the choroid is visible through it; but the bacillar layer is everywhere continuous, the ordinary 'rods,' however, having their places entirely occupied by the 'cones,' whose extremities abut upon the external surface, instead of being removed from it as elsewhere.—Now it is not a little remarkable, that the point of the entrance of the Optic nerve should be deficient in the power of receiving distinct visual impressions (§ 623); whilst the 'yellow-spot' is the most sensitive portion of the entire Retina. And hence it seems unequivocally to follow, that these impressions cannot act primarily upon the nerve-fibres;—a conclusion which harmonizes with the fact, that the fibres of the optic nerve are superimposed upon each other in the stratum which they form, in such numbers that it is not conceivable that they should be the primary recipients of luminous impressions, since their transparency must allow rays of light to penetrate from one portion of the layer to another. The bacillary layer was formerly regarded as a reflecting apparatus, having for its purpose to stop the further passage of light, and to intensify its influence on the true retina; but since its connection with the proper nervous elements of the retina has been established, there seems much ground for believing (with Prof. Kölliker) that its rods and cones are the primary recipients of luminous impressions, and that they communicate their condition to the fibres of the optic nerve, by means of their own delicate fibrous prolongations, which seem to come into more or less direct connection with its ultimate ramifications. This supposition harmonizes well with the idea recently put-forth, that the obliquity of the rods is such as to make them all point towards 'the centre of direction' of the visual rays (§ 610); and that it is through this instrumentality, that we are guided in our appreciation of the relative directions of different objects, as Articulated animals probably are by the impressions made on the individual ocelli of their compound eyes, since the

FIG. 133.



Distribution of Capillaries in the Vascular layer of the *Retina.*

FIG. 134.



Part of external surface of *Retina of Frog*, showing the imbricated arrangement of the extremities of the rods of 'Jacob's Membrane.'

object whose rays pass-down any one of these, must always be in the direction of its axis.*

607. The *limits* of Human Vision, as regards the minuteness of the objects of which it can take cognizance, have been investigated by Prof. Ehrenberg, with the view of calculating the ultimate power of the Microscope.† In opposition to the generally-received opinion, Ehrenberg arrived at the conclusion that, in regard to the extreme limits of vision, there is little difference amongst persons of ordinarily-good sight, whatever may be the focal distance of their eyes. The smallest square magnitude usually visible to the naked eye, either of white particles on a black ground, or of black upon a white or light-coloured ground, is about the 1-405th of an inch. It is possible, by the greatest condensation of light, and excitement of the attention, to recognize magnitudes between the 1-405th and 1-540th of an inch, but without sharpness or certainty. Bodies which are smaller than these cannot be discerned with the naked eye when single, but may be seen when placed in a row. Particles which powerfully reflect light, however, may be distinctly seen, when not half the size of the least of the foregoing; thus, gold dust‡ of the fineness of 1-1125th of an inch, may be discerned with the naked eye in common daylight. The delicacy of vision is far greater for *lines* than for mere points; since opaque threads of 1-4900th of an inch in diameter (about half the diameter of the Silk-worm's fibre) may be discerned with the naked eye, when held towards the light. The size of the retinal image in these cases must be exceedingly small. In some of Bergmann's experiments it was found that black and white chequers of 1-25th of an inch square could be discerned at such a distance that the retinal image of each square could not have exceeded half the diameter of one of the cones of the bacillary layer.§—The degree in which the *attention* is directed to them, has a great influence on the readiness with which very minute objects can be perceived; and Ehrenberg remarks that there is a much greater difference amongst individuals in this respect, than there is in regard to the absolute limits of vision. Many persons can distinctly see such objects, when their situation is exactly pointed-out to them, who cannot otherwise distinguish them; and the same is the case with persons of acuter perception, with respect to objects at distances greater than those at which they can see most clearly. "I myself," says Ehrenberg, "cannot see 1-2700th of an inch, black or white, at twelve inches' distance; but having found it at from four or five inches' distance, I can remove it to twelve inches, and still see the object plainly." Similar phenomena are well known in regard to a balloon or a faint star in a clear sky, or a ship in the horizon: we easily see them after they have been pointed-out to us; but the faculty of readily descrying objects depends on the habit of using the eyes in search of them, and of attending to the sensory impressions thus received (§ 626).

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* See the very ingenious "Essai sur les Phosphènes," by Dr. Serre, Paris, 1853.

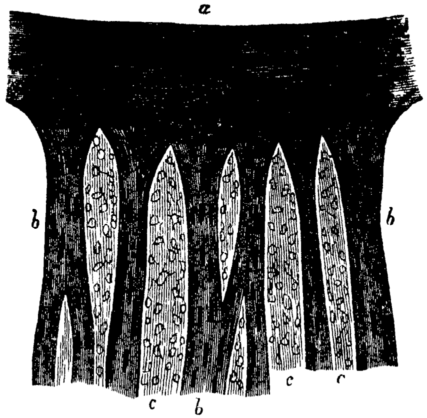
† Taylor's "Scientific Memoirs," vol. i. p. 576. See also Helmholtz, "Physiolog. Optik.," 1860.

‡ Ehrenberg mentions that he obtained the finest particles of gold, by scraping gilt brass; by filing pure gold, he always obtained much coarser particles.

§ Henle and Meissner's "Bericht," 1857, p. 559.

608. The amount of light admitted to the Eye is regulated by the contraction and dilatation of the Pupil, the smallest diameter of which is about 1-20th, and its largest about 1-3rd of an inch. The muscular structure of the Human *Iris* is entirely of the non-striated kind, being composed of the elongated fibre-cells with staff-shaped nuclei which are characteristic of that variety. Part of these are so disposed as to form a circular sphincter (Fig. 135, *a*), which can be readily seen in the iris of the white rabbit, or in the blue iris of man from which the uvea has been removed, immediately surrounding the pupillary margin to the breadth of about one-third of a line. The fibres of this sphincter are not absolutely parallel, especially at the outer margin, where they seem to become continuous with those of the radiating fasciculi (*b*, *b*), which may be traced from this sphincter (though usually with difficulty) to the outer margin of the iris, sometimes anastomosing with each other in their course.[*] The contraction of the annular fibres, whereby the diameter of the pupil is *diminished*, is effected, as already explained (§ 496), through the instrumentality of the Third pair of nerves; the contraction of the radiating fibres, on the other hand, whereby the pupil is *dilated*, is under the government of the cervical portion of the Sympathetic, being called-forth (as MM. Budge and Waller have shown[†]) by irritation of the trunk of the Sympathetic in the neck, or of the lower part of the cervical portion of the Spinal Cord, by the magneto-electric apparatus; whilst section of the Sympathetic produces a permanent contraction of the pupil, the action of the Third pair being then no longer antagonized. It appears from other experiments, that the fibres through which this movement is effected, pass through the Gasserian ganglion, and are distributed to the eye by the ophthalmic branch of the Fifth pair (§ 477). The contraction of the Pupil answers the purpose, as we have seen, not merely of excluding superfluous light from the eye, but also of cutting off the most divergent rays when the object is brought near the refracting surface (§ 603), and of thus preventing the indistinctness of vision

Fig. 135.



Muscular structure of the Iris of a White Rabbit:—*a*, sphincter of the pupil; *b*, *b*, radiating fasciculi of dilator muscle; *c*, *c*, connective tissue with its corpuscles.

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[*] See Prof. Kölliker's "Mikroskopische Anatomie," band ii. § 272; and Jos. J. Lister's 'Observations on the Contractile Tissue of the Iris,' in "Quart. Journ. of Microscop. Science," vol. i. p. 8.

[†] "Gazette Médicale," 1851, Nos. 41, 44.

which would result from their admission. For although, when the Eye is at rest, parallel rays come to a focus on the Retina, divergent or convergent rays proceeding from any point come to a focus either behind or in front of that membrane, forming upon it what is termed a "circle of dissipation"; but by cutting off the outermost rays and permitting the entrance of those only which are nearly parallel, the magnitude of such circles is materially diminished, and vision correspondingly improved. It is interesting to observe that contraction of the pupil is effected with greater rapidity than dilatation, a matter of some importance in sudden alternations from light to darkness.—M. Brown-Séquard* has shown that the Irides of various animals may be directly affected by Heat and Light. Thus if the eyes of dogs, cats, or rabbits, either soon after death or shortly after their removal from the body, be suddenly exposed to an alteration of temperature amounting to 50° or 60° F., if the pupil be contracted, it expands, though on the contrary, if it be in the first instance dilated, it speedily contracts. These effects of heat have not been observed either in Man or the Mammalia during life. As regards the direct action of Light, Brown-Séquard found that the Irides of eels and frogs which had been removed for several (even sixteen) days from the body in winter, as well as the Irides of mammals and birds for a short time after death, contracted on exposure to the light of the sun or of a candle; this effect being produced even when the posterior half of the eye had been cut off, and when, therefore, there could have been no reflex action. The yellow rays appeared to have the greatest energy. These remarkable phenomena prove, at all events, that the contraction of the pupil is not, as has occasionally been maintained, exclusively due to vascular turgescence. The cause of the effect produced by Light is difficult to explain, but that occasioned by Heat may perhaps be attributed, as Brown-Séquard suggests, to the circumstance that a contracted muscle has less power than one in a state of extension, so that if a stimulus act equally on both, when previously nicely balanced in point of strength, the uncontracted muscle will exert the greater force, and consequently overpower the contracted muscle.

609. The sense of Vision depends, in the first place, on the excitement of our sensational consciousness by the ocular picture impressed upon the retina, which represents the outlines, lights and shades, colours, and relative positions of the objects before us; and all the ideas respecting the real forms, distances, &c. of bodies, which we found upon these data, are derived through the perceptions, either instinctively or experientially suggested by sensations. Many of these ideas are derived through the combination, in our minds, of the Visual perceptions, with those derived from the sense of Touch. Thus, to take a most simple illustration, the idea of *smoothness* is one essentially tactile; and yet it constantly occurs to us, on looking at a surface which reflects light in a particular manner. But if it were not for the association which experience leads us to form, of the connection between *polish* as seen by the *eye*, and *smoothness* as felt by the *touch*, we should not be able to determine, as we now can do, the existence of both these qualities, from an impression communicated to us through either sense singly.—The general fact that, in Man, the greater part of those notions of the external world, by which his actions

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* "Journal de la Physiologie," 1859, vol. ii. p. 294.

in the adult state are guided, are acquired by the gradual association of the two sets of perceptions derived through the Sight and through the Touch, is substantiated by amply-sufficient evidence; this being chiefly derived from observations made upon persons born blind, to whom sight has been communicated by an operation, at a period of life which enabled them to give an accurate description of their sensations. The case recorded by Cheselden is one of the most interesting of these. The youth (about twelve years of age), for some time after tolerably-distinct vision had been obtained, saw everything *flat* as in a picture, simply receiving the consciousness of the impression made upon his retina; and it was some time before he acquired the power of judging, by his sight, of the real forms and distances of the objects around him. An amusing anecdote recorded of him, shows the complete want which there is in Man, of any natural or intuitive connection between the ideas formed through visual and through tactile sensations. He was well acquainted with a Dog and a Cat by *feeling*, but could not remember their respective characters when he *saw* them; and one day, when thus puzzled, he took up the Cat in his arms, and felt her attentively, so as to associate the two sets of ideas, and then, setting her down, said, "So puss, I shall know you another time."—A similar instance has come under the Author's own knowledge; but the subject of it was scarcely old enough to present phenomena so striking. One curious circumstance was remarked of him, which fully confirms (if confirmation were wanting) the view here given. For some time after his sight was tolerably clear, the lad preferred finding his way through his father's house (to which he had been quite accustomed when blind) by touch rather than by sight, the use of the latter sense appearing to perplex instead of assisting him; but, when learning a new locality, he employed his sight, and evidently perceived the increase of facility which he derived from it.*—The actions performed by many new-born animals do not constitute any valid objection to the view that such visual perceptions are for the most part *acquired* by Man; for all that is indicated by them is, that certain sensations give-rise to movements adapted to supply the wants to which they relate; and they do not afford any proof that definite notions, such as we entertain, of the forms and properties of external objects, are possessed by the animals which exhibit them.—We shall now examine, a little more in detail, into the means by which we gain such notions, and the data on which they are founded.

610. The first point to be determined, is one which has been a fruitful source of discussion,—the cause of *erect vision*, the picture upon the retina being inverted; and with this is connected the general question of the origin of our *Sense of Direction*.—The difficulty which has been raised in regard to the former subject, is rather apparent than real; being founded on an erroneous notion of the nature of the Visual sense. For it seems to have been supposed that we *look at* the retinal picture with the 'mind's eye,' just as we look at the picture formed by a Camera with the bodily eye; and that our consciousness must be therefore impressed

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* The question has been proposed, whether a person born blind, who was able by the sense of Touch to distinguish a cube from a sphere, would, on suddenly obtaining his Sight, be able to distinguish them by the latter sense. This question was answered by Locke in the negative; and, as appears from the facts above stated, with justice.

by its discordance with the information which we receive through our sense of Touch. Some philosophers, indeed, have actually gone so far as to assert that the Infant must at first see everything inverted, and that the erectness of visual objects is only learned by the corrective experience gained by touching and handling them. But such is clearly not the case; for the visual perception is obviously not a mere *transfer* of the sensorial impression, but is a *mental state excited by it*, and therefore related to it as an effect to its cause; and we know no reason why it should be *less natural* for the retinal picture to *suggest to the mind* the notion of *erect* position, than for it to have the contrary effect. Moreover, it will appear from recent investigations to be hereafter detailed (§ 624), that there is in the eye a common 'centre of direction,' through which all lines must pass, that are drawn from any points of an external object to the corresponding points of its retinal image;* and that we immediately refer the cause of the excitation of any spot of the retina by a luminous impression, to an objective source in the 'line of direction' which passes from that spot through the centre of direction; so that, in virtue of this 'law of visible direction,' as all the lines of direction cross each other both vertically and laterally, the formation of an inverted image upon our retina suggests to our minds the representation of the object in its erect position, and the same reversal takes-place also in regard to its two sides, which are transposed in the retinal picture. A peculiar arrangement of the receptive apparatus, which seems to be subservient to this mental appreciation of direction, has been already noticed (§ 606).

611. The cause of *Single Vision with the two Eyes* has, in like manner, been the subject of much discussion; and here, too, the difficulty is rather apparent than real, having for its foundation the idea that the mind looks at the two retinal pictures as at two separate objects, instead of being impressed by a certain state of the Sensorium, which may be excited through the instrumentality of either eye, or through that of both in combination. Some have even asserted, under the influence of this idea, that we do not really employ both eyes simultaneously, but that the mind is affected by the image communicated by one only; which might seem to be confirmed by the fact sufficiently well ascertained respecting the alternate use of the two eyes, when they are looking through two differently-coloured media. But of this assertion a complete disproof is afforded by the knowledge we now possess (§ 612), that our appreciation of the solid forms of bodies depends on the combination, *by the Mind*, of the images simultaneously suggested by the two pictures; and that our knowledge of distances is in great part obtained in like manner.—Attempts have been made to explain the phenomena of Single Vision by the peculiar decussation of the Optic Nerves formerly

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* With regard to the precise situation of this 'centre of direction,' there is a want of accordance among those who have attempted to determine it; some having placed it in the centre of the pupil, others in the centre of the crystalline lens, others at various distances between this and the centre of the globe, and others (among them Sir D. Brewster) *in* the centre of the globe. This last notion, with the 'law of visible direction' founded upon it,—which affirms that every object is seen in the direction of the perpendicular (or radius) to every point of the retina which is impressed,—is so manifestly wrong, that it is difficult to conceive how it could ever have been entertained by men of science. The experimental investigations of Dr. Serre (§ 624) lead him to regard the centre of the crystalline as the 'centre of direction.'

described (§ 506); it being supposed that only one Optic Ganglion would be affected by an impression made upon both Retinæ.* This explanation, however, even supposing the fact to be as stated, would be far from affording the solution of the problem; and it would be entirely inapplicable to that very important series of phenomena to be next described, which show how large an amount of information we derive, not from the *repetition*, but from the *difference*, of the sensory impressions made by the same object upon our two retinæ; and which indicate that here, as in the case of erect vision, the *mental interpretation* of the sensory impressions is a process altogether removed from the simple affection of the consciousness by those impressions, and is not to be accounted-for by any structural arrangements of the Sensorial apparatus. One condition of Single Vision, however, seems to be this, that the two images of the object should be formed on parts of the two retinæ which are *accustomed* to act in concert; and *habit* appears to be the chief means by which this conformity is produced. There can be no doubt, however, that double images are continually being conveyed to the Sensorium; but that, from their want of force and distinctness, and from the attention being fixed on something else, we do not take cognizance of them. This may be shown by a very simple experiment. If two fingers be held-up before the eyes, one in front of the other, and vision be directed to the more distant, so that it is seen singly, the nearer will appear double; while, if the nearer one be regarded more particularly, so as to appear single, the more distant will be seen double. A little consideration will show, therefore, that our minds must be thus continually affected with sensations, which cannot be united into the idea of a single image; since, whenever we direct the axes of our eyes towards any object, almost everything else will be represented to us as double; but we do not ordinarily perceive this, from our minds being fixed upon a clear and distinct image, and disregarding, therefore, the vague undefined images formed by objects not in the visual focus. Of this it is very easy to satisfy one's-self. It has been found by Gehler, J. Muller, and others, that those objects which do not appear double when a given point is fixedly regarded are situated in a certain circular line, termed the Horopter, of which the chord is formed by the distance between the eyes, whilst the magnitude of the circle is determined by three points—namely, by the two eyes and the point towards which their axes converge. Prof. Helmholtz, however, considers that generally the Horopter is a line of double curvature, produced by the intersection of two hyperboloids, or, exceptionally, of two plane curves; and that when we look straight forward to a point of the horizon, the Horopter becomes a horizontal plane passing through our feet—being, in fact, the ground on which we are standing. The form and situation of the Horopter appear to be of great practical importance in enabling us to judge with accuracy of the shape and distance of those objects which are situated in it.*—The above experiment, moreover, makes it evident that double vision cannot result from *want of symmetry* in the position of the images upon the retina, to which some have attributed it; for it answers equally well, if the line of the two fingers be precisely in front of the nose, so that the inclination of both eyes towards either object is equal; the position of the images of the second object must then be at the same distance on either side from the central line of the retina, and yet they are represented to the mind as double. Hence, too, it seems clear that singleness of vision in an object that is *looked-at*, is also dependent in part upon the *convergence of the optic axes* in that object (§ 603); and that this is the case appears further from a curious experiment devised by Prof. Wheatstone, in which two similar objects are made to seem as one, when they are placed in the line of convergence. This is accomplished by looking through two tubes, placed before the right and left eyes respectively, at two similar objects of any description, placed near the farther extremities of the tubes; if, now, these objects be slightly approximated, so that the axes of the tubes (still directed towards them) meet in a point beyond, the mind is impressed with the image of only a single object, and this appears to be removed-back to the point of convergence.

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* This decussation seems to be even more complete than was formerly supposed, for in various experiments made by Dr. Waller upon the effects of section of one optic nerve, it was found that the *Optic Tract* upon the same side as the lesion, showed no signs of degeneration, whilst that of the opposite side soon underwent disorganization with the exception of a few strands on the inner and posterior aspect; thus countenancing the opinion that there are commissural fibres passing between the corpora quadrigemina of the two sides, but negativing the view that some of the fibres from each retina run to the corpora quadrigemina on their own side. Dr. Waller is inclined to think, therefore, that the decussation is complete. It is important to observe, that in these experiments the anterior portion of the divided nerve, with the retinal elements, remained unchanged for many weeks. See "Proceedings of the Royal Society," vol. viii. On the other hand, the reader may refer to some curious cases of partial Amaurosis recorded by Mr. Towne in the "Guy's Hospital Reports" for 1863, p. 127.

612. On the mode in which our notion of the *solid forms* and *relative projection* of objects is acquired, great light has been thrown by the interesting experiments of Prof. Wheatstone.† It seems perfectly evident, both from reason and experience, that the flat picture upon the retina, which is the immediate source of our sensation, could not itself convey to our minds any notion, but that of a corresponding plane surface. In fact, any notion of *solidity*, which might be formed by a person who had never had the use of more than one eye, would entirely depend upon the combination of his visual and tactile sensations. This view is fully confirmed by the case already referred-to (§ 609), as recorded by Cheselden. The first visual idea entertained by the youth was, that the objects around him formed a flat surface, which touched his eyes, as they had previously been in contact with his hands; and after this notion had been corrected, through the education of his sight by his touch, he fell into the converse error of supposing that a picture, which was shown to him, was the object itself represented in relief on a small scale.—But where both eyes are employed, it has been ascertained by Prof. Wheatstone, that they concur in exciting the perception of solidity or projection, which arises from the *mental* combination of the two *dissimilar* pictures formed upon the two retinæ. It is easily shown, that any *near* object is seen in two different modes by the two eyes. Thus let the reader hold-up a thin book, in such a manner that its back shall be exactly in front of his nose, and at a moderate distance from it; he will observe, by closing first one

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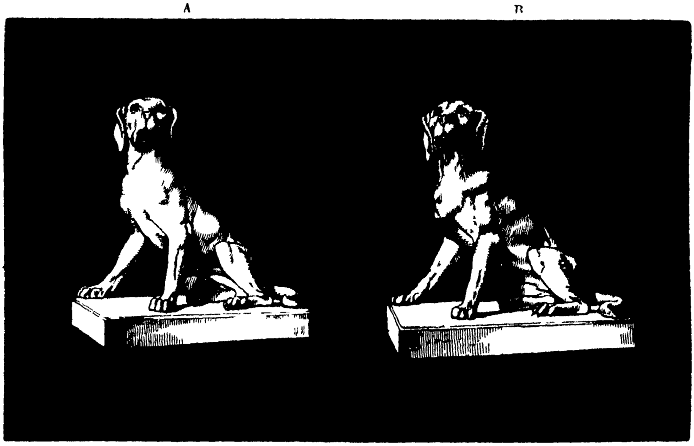
* See Müller's "Physiology," translated by Dr. Baly, vol. ii. p. 1196; also the Croonian Lecture for 1864, delivered before the Royal Society, by Professor Helmholtz, in vol. xiii. of the "Proceedings of the Royal Society."

† "Philosophical Transactions," 1838 and 1852.

eye and then the other, that his perspective view of it (or the manner in which he would represent it on a plane surface) is very different, according to the eye with which he sees it. With the right eye he will see its right side, very much fore-shortened; with the left, he will gain a corresponding view of the left side; and the apparent angles, and the lengths of the different lines, will be found to be very different in the two views. On looking at either of these views singly, no other notion of solidity can be acquired from it, than that to which the mind is conducted, by the association of such a view with the touch of the object which it represents. But it is capable of proof, that the mental association of the *different* pictures upon the two retinæ, does of itself give rise to the idea of solidity. This proof is afforded by Prof. Wheatstone's ingenious instrument, the Stereoscope, first described by him in 1838.*

613. The *Stereoscope* in its original form essentially consists of two plane mirrors, inclined with their backs to one another at an angle of 90°. If two perspective drawings of any solid object, as seen at a given distance with the two eyes respectively, such as those at A and B, Fig. 136, be so placed before these mirrors, one before each, that their two images shall be made to fall upon the corresponding parts of the two retinæ, in the same manner as the two images formed by the solid object

FIG. 136.



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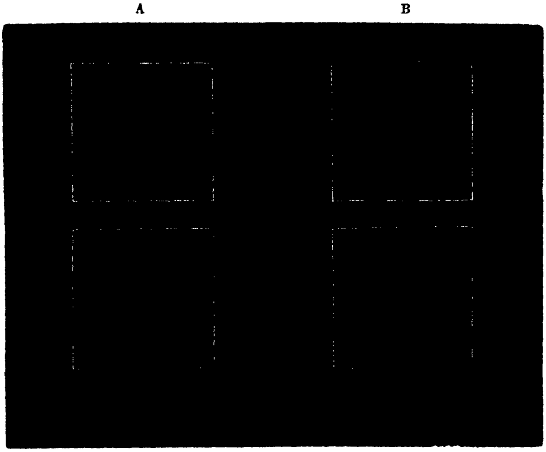
* Various modifications of this instrument have been subsequently introduced; and there is one which has recently (1851) come into very extensive use, in which the two monocular pictures placed side by side, as in Figs. 136, 137, are viewed by the two eyes respectively through two halves of a convex lens. The great advantage of this instrument is its portability, and its enlargement of the pictures by the magnifying power of the lenses; but it is limited to pictures of small size, since the distance between corresponding points of the two pictures must not exceed the distance between the centres of the two eyes; and it is incapable of many adaptations which can be made with the mirror-stereoscope.—In the Stereomonoscope of Claudet the idea of relief is obtained by looking with both eyes at once on a ground-glass plate at the image produced by the coalescence of the two images of a stereoscopic slide, each refracted by a separate lens. See "Proceed. of Royal Society," vol. ix. 1857-59, p. 194.

itself would have done, the mind will perceive, not a single representation of the object, nor a confused blending of the two, but a projecting or receding surface, the exact counterpart of that from which the drawings were made.* The solid form is forcibly impressed on the mind, even when outlines only are given, especially if these be delineations of simple geometrical figures, easily suggested to the mind; and it may be readily shown that the very same outlines will suggest different conceptions, according to the mode in which they are placed. Thus in Fig. 137, the

FIG. 137.



upper pair of figures, A, B, when combined in the Stereoscope, excite the idea of a *projecting* truncated pyramid, with the small square *in the centre*, and the four sides sloping equally *away from* it; whilst the lower pair of figures, C, D, which are the same as the upper, but transferred to the opposite sides, no less vividly bring before the mind the visual conception of a *receding* pyramid, still with the small square in the centre, and the four sides sloping equally *towards* it.—Prof. Wheatstone has further shown, by means of the Stereoscope, that similar images, differing to a certain extent in magnitude, when presented to the corresponding parts of the two retinæ, give-rise to the perception of a single object, intermediate in size between the two monocular pictures. Were it not for this, objects would appear single only when at an equal distance from both eyes, so that their pictures upon the retina are of the same size; which will not happen unless they are directly in front of the median line of the face. Again, if pictures of dissimilar objects be simultaneously presented to the two eyes, the consequence will be similar to that which is experienced when the rays come to the eye through two differently coloured media; the two images do not coalesce, nor do they appear permanently superposed one upon the other; but at one time one image predominates to the exclusion of the other, and then the other is seen alone; and it is only at the moment of change that the two seem to be intermingled. It does not appear to be in the power of the Will, Prof. Wheatstone remarks, to determine the appearance of either; but if one picture be more illuminated than the other, it will be seen during a larger portion of the time. If, however, the differences in the two pictures be such that the Mind can reconcile them, an *intermediate* conception is formed; thus if two photographic portraits be taken at the proper angle for the Stereoscope, not simultaneously but consecutively, and the 'sitter' alter his expression in the interval, so that one of the portraits represents him with a smile, and the other with a frown, the Stereoscopic image will present an intermediate expression of placidity.—Many other curious experiments with this simple instrument are related by Prof. Wheatstone; and they all go to confirm the general conclusion, that the combination of the dissimilar images furnished by the two eyes is *a mental act*, the resultant of which, in the case of all objects that are near enough to be seen in different perspective with the two eyes, is a mental image (referred to the visual sense) possessing the attributes of solidity and projection. In regard to distant objects, however, the difference in the images formed by the two eyes is so slight, that it cannot aid in the determination; and hence it is, that whilst we have no difficulty in distinguishing a picture, however well painted, from a solid object, when placed near our eyes (since the idea which might be suggested by the image formed on one eye will then be corrected by the other),* we are very liable to be misled by a delineation in which the perspective, light and shade, &c., are faithfully depicted, if we are placed at a distance from it, and are prevented from perceiving that it is *but* a picture.† In this case, however, a slight movement of the head is sufficient to undeceive us; since by this movement a great change would be occasioned in the perspective view of the object, supposing it to possess an uneven surface; whilst it scarcely affects the image formed by a picture. In the same manner, a person who only possesses one eye, may obtain, by a slight motion of his head, the same idea of the form of a body which another would acquire by the simultaneous use of his two eyes.‡

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* The most striking effect is produced by two Photographic pictures, taken at the same time by two cameras, so placed that their axes shall form the same angle with each other as that which the axes of the two eyes would form when looking at the same object. This adaptation, though the credit has been assumed by others, was originally devised by Prof. Wheatstone.

614. Our appreciation of the relative Distances of *near* objects seems to be derived in like manner from the mental combination of the perceptions derived from the dissimilar pictures upon the two retinæ, assisted by the sensations derived from the muscles of the eyeballs, which are put

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* It is a remarkable illustration of this principle, that a photographic representation of a landscape, building, &c., when viewed with *one eye* at a moderate distance, frequently brings the real scene far more forcibly before the mental vision than when it is looked-at with both eyes; since, in the latter case, the mind cannot avoid perceiving the flatness of its surface; whilst, in the former, the perspective, and the distribution of the lights and shadows, are free to suggest to the mind the relative distances and projections of the several parts.

† This delusion has been extremely complete, in some of those who have seen the panoramic view of London in the Colosseum. A lively and interesting account of it is given in the Journal of the Parsee Shipbuilders, who visited England some years ago.

‡ For many interesting experiments with the stereoscope, see Mr. T. Towne in "Guy's Hospital Reports" for 1862 and 1863.

in action to bring the optic axes into the requisite convergence. How much our right estimation of the relative distances of objects not too far removed from the eye, depends upon the joint use of *both eyes*, is made evident by the fact, that, if we close one eye, we find ourselves unable to execute with certainty many actions (such as threading a needle, or snuffing a candle) which require its guidance. In proportion as the object is approximated to the eyes, slight differences of distance produce marked differences in the degree of convergence, and these are readily appreciated so as to afford the means of very nice discrimination; whilst, on the other hand, in proportion as they are removed further and further, do the optic axes approach parallelism, and the power of appreciating differences of distance is lost. It is the usual opinion that the muscular sensation which accompanies the inclination of the optic axes, *immediately suggests* the notion of the *distance* of an object; and that our appreciation of its *size* depends upon a secondary *interpretation* of the magnitude of its picture on the retina, on the basis of this notion. But it would appear from the experiments of Prof. Wheatstone, that the reverse is the case; the sensation of convergence assisting in the first instance to determine the size, and the appreciation of distance being a secondary judgment based on this foundation (§ 617).—The power of estimating distance from the foregoing data, however, is obviously, in Man, not an intuitive but an acquired endowment; for it is evident to any observer, that infants, or older persons who have but recently acquired sight, form very imperfect ideas respecting the distance of objects; their attempts to grasp bodies which attract their attention being for a long time unsuccessful, so that they only gradually learn to measure distances by the sight, through the medium of the touch. And it seems to follow from this, that even the notion of 'projection,' which we seem necessarily to form when looking at a solid object within a moderate distance, or at a properly-adjusted pair of Stereoscopic pictures, is not derived from an original intuition, but is the result of the association of our visual with our tactile experience, very early in life, so as to constitute a 'secondary intuition' on which all our subsequent appreciation of projection is based.

615. In regard to *remote* objects, our judgment of Distance is chiefly founded upon their apparent size, if their actual size be known to us; but, if this be not the case, and if we are so situated that we cannot judge of the intervening space, we principally form our estimate from that effect of different degrees of remoteness upon the distinctness of their colour and outline, which is known to Artists as 'aerial perspective.' Hence this estimate is liable to be greatly affected by varying states of the atmosphere, as is particularly known to every one who has visited warmer climates; where the extreme clearness of the air sometimes brings into apparently-near proximity a hill that rises some miles beyond a neighbouring ridge (the intervening space being hidden, so as not to afford any datum for the estimate of the distance of the remote hill), whilst a slight haziness carries its apparent distance to three or four times the reality. Additional means of judging of the distance of remote objects pointed-out by Aubert,* are found in their parallax or apparent change of place, on the alteration of our own position with regard to them, and in the rate of

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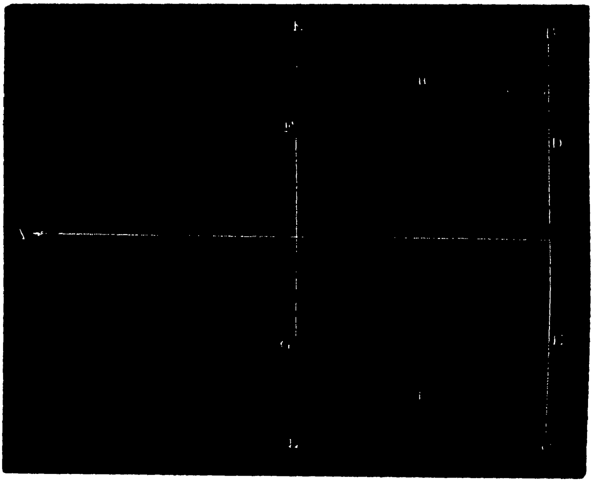
* "Physiologie der Netzhaut," 1864, p. 17.

movement, both absolute and relative, of the objects themselves, if they happen to be in motion.

616. Our estimate of the Size of a *remote* object is partly dependent upon the *visual angle* under which we see it, and partly upon our estimate of its *distance*.* The 'visual angle,' formed by imaginary lines drawn from the eye (Fig. 138, A) to the extreme points, B, C, of the object, is the measure of the dimension of its image upon the retina; and it is obvious that, if two objects, B C, D E, the former twice the length of the latter, be placed at the same distance, the visual angle B A C being twice as great as the angle D A E, the image of B C upon the retina will be twice as long as that of D E, and the mind will estimate their relative sizes accordingly. But if the distance of the object D E from the eye be diminished to one-half, so that it is brought into the position F G, its visual angle, and consequently the size of its image on the retina, will now be equal to that of B C; and the estimate we form of the relative sizes of the two, will entirely depend upon the idea we entertain of their relative distances. Hence any circumstance which modifies that idea, produces a corresponding difference in our estimate of their size; so that the apparent size of an object, seen under a given visual angle, may be estimated as larger or smaller than the reality, according as we suppose it to be more or less distant than it really is. Of this we have a familiar instance in the fact, that if we meet a child whilst we are walking across a common in a fog (the flatness of the ground not giving us much power

FIG. 138.



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* When objects are so remote that we have no means of even approximately estimating their *distance*, we have no measure whatever of their *size*. Thus, the Sun and the Moon are of nearly the same apparent size to us, though one is about four hundred times the distance of the other; and we may cover either disc with a sixpence held near the eye, so as to be seen under the same visual angle; but we do not possess the least power of estimating the actual sizes of these objects, save by a calculation based on a knowledge of their relative distances.

of estimating the intervening space), it appears to have the stature of a man, and a man seems like a giant; for the indistinctness of outline causes the mind to conceive of the figures as at a greater distance than they really are, and their apparent dimensions are augmented in like proportion. For if the object F G (Fig. 138) be *mentally carried-back* to the distance of D E, being still seen under the visual angle F A G (or B A C), it will appear to possess the length B C instead of D E. On the other hand, if the object B C were to be *mentally brought-forward* into the position K L, its apparent size being still determined by its visual angle, it will seem to be reduced to the length F G.

617. That our estimate of the Size of *near* objects, however, depends upon a more direct process, seems to be a necessary inference from the following very ingenious experiments, made by Prof. Wheatstone with a modification of his Mirror-Stereoscope, devised for separately testing the influence of the two conditions,—namely, the magnitude of the retinal picture, and the degree of convergence of the optic axes,—which are ordinarily in action together. When an object is moved nearer-to or farther-from the eye, its *perceived* or estimated magnitude undergoes no change. But if two pictures, placed in the mirror-stereoscope, be made to move to and from the mirrors, in such a manner as to vary their *distances* from these (and therefore from the eyes), without altering the angle of convergence, their perceived magnitudes are augmented and reduced, in precise proportion to the increased and diminished sizes of the retinal pictures. Conversely, if the two pictures be made so to change their places in regard to the mirrors (by moving in a horizontal circle, of which the middle-point between the mirrors is the centre), that the *angle of convergence* is increased or diminished, as it would be if the object were brought nearer to the eyes or removed farther from them, the perceived magnitude of the pictures is altered in an inverse manner; being reduced when the angle of convergence is increased, and increased when the inclination of the optic axes is lessened so as to approach parallelism. Thus it appears that the absence of alteration in the perceived magnitude of an object as ordinarily seen at varying distances, is the result of the inverse action of these two kinds of suggestion; for the enlargement of the retinal picture, when acting alone, occasions an increase in the perceived magnitude, whilst an increase of convergence, taking-place by itself, diminishes the perceived magnitude; and thus, as these alterations occur simultaneously when an object is approximated to the eye, its dimensions seem to undergo no change; as will also be the case when, by the removal of the object to a greater distance, these conditions are again made to vary simultaneously, though in a contrary direction.—It may further be remarked, that in the first of the foregoing experiments, the picture whose perceived magnitude is undergoing enlargement or diminution in consequence of the alteration of its retinal magnitude, seems evidently to be approaching or receding; yet if we fix our attention on it when it is stationary, at any instant, it appears to be at the same distance at one time as at another,—the effect being very much like that of the Phantasmagoria, in which the alteration in the size of the images on the screen suggests the notion of their approach or recession, although we are quite sensible that the distance of the screen from our eyes remains constantly the same. In the second experiment, on the other hand, the

picture whose perceived magnitude is undergoing diminution or enlargement in consequence of increase or lessening of the angle of convergence, does not appear either to approach or recede, and yet, when attentively regarded in different fixed positions, it is felt to be at different distances. Hence, as Prof. Wheatstone observes, convergence of the optic axes suggests fixed distance to the mind, whilst variations of retinal magnitude suggest change of distance; and, however paradoxical it may seem, "we may perceive an object approach or recede, without appearing to change its distance, and an object to be at a different distance without appearing to approach or recede."*—A like alteration in apparent size is produced, when two pairs of figures (such as those given in Fig. 137), the effect of one of which is to suggest a *projecting*, and that of the other a *receding* form, are viewed at the same time in the ordinary Stereoscope. For it will be observed that the relative size of the parts which appear to project is reduced, whilst that of the apparently-receding parts is augmented; as is particularly the case with the square truncated end of the pyramid, which is estimated by most persons as from one-third to one-half larger in each of its dimensions in the receding, than it is in the projecting pyramid, notwithstanding that the actual sizes of the squares in the two sets of figures are precisely the same. For supposing H I (Fig. 138) to represent the real side of one of the small squares, which becomes the truncated end of the pyramid; when this is brought-forward by the mind into the position K L, as the truncated top of a projecting pyramid, being seen under the visual angle H A I, its apparent size is reduced to F G; whilst, on the other hand, the very same square, carried-back by the mind to the distance D E, as when it forms the truncated end of the receding pyramid, is mentally enlarged to the dimensions B C, the visual angle B A C being the same as H A I.

618. The large share which the Mind has in the interpretation of even such visual impressions as seem to us *necessarily* to induce particular perceptions, is further shown by a very remarkable class of phenomena, termed by Prof. Wheatstone (their discoverer) *Conversions of Relief.* The simplest example of this class is presented by the alteration in the visual product of the same Stereoscopic pictures, when their positions are transposed. Thus the very same diagrams, which, as placed in the upper part of Fig. 137, bring before the mind's eye the conception of a projecting pyramid, when changed to the position which they occupy in the lower part of that figure, call-up the image of a receding pyramid. And a corresponding effect is produced by the reversal of any other pair of Stereoscopic pictures; all that should project being made to recede, all that should recede being made to project, *provided the converse has any meaning* which the Mind can readily appreciate.—But the same effects may be produced, if the objects themselves are looked-at by an instrument devised by Prof. Wheatstone, and termed by him the *Pseudoscope;* the optical effect of which is, to reverse the ordinary visual relations between the near and distant parts of an object; the two conditions described in the preceding paragraph being combined inversely, so that,

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* See "Philos. Transact.," 1852, pp. 2-5. The Author thinks it well to add, that he has himself verified the above very curious results; which are scarcely less valuable contributions to the Physiology of Binocular vision, than those earlier attained by the same eminent experimentalist.

as an object or part of an object is nearer the eye, its larger picture on the retina is accompanied by a diminished convergence of the optic axes. When the impression of a seal is looked-at with this instrument, it is converted into the representation of the seal itself; or, if the seal be looked-at, it presents the figure raised in relief, as in its ordinary impression. So, the inside of a cup or basin appears as a solid convex body; whilst the outside appears depressed and concave. A bust regarded in front becomes a deep hollow mask; whilst the interior of the cast of a face presents the appearance of the face in its ordinary relief. A china vase, ornamented with coloured flowers in relief, seems like a vertical section of the interior of such a vase, with hollow impressions of the flowers. The base of a brain seems concave, like the interior of the base of the skull which is its reflex; and the latter seems convex and projecting, like the base of the brain.—These and similar appearances are not always immediately perceived; and some present themselves much more readily than others. Those converse forms which we are *accustomed* actually to see, or which have a *meaning* that the mind can easily apprehend, are those which are most readily perceived. Thus, the illusion which may be produced with a bust or with the cast of a face, is not obtainable even by a lengthened pseudoscopic contemplation of the *real* face, which we cannot conceive-of as thus 'turned inside-out.' Another very interesting fact is, that those to whom the illusion does not at first present itself, usually find it *suddenly* come upon them after a little time, especially if they should have directed their minds to the imaginary conception of the object under its changed aspect. And, further, when the conversion has taken place, the natural aspect of the object continues to intrude itself, sometimes suddenly, sometimes gradually, and for a longer or shorter interval, when the converse will again succeed it. This is due to the involuntary alternation of the attention, between the conception suggested to the mind by the visual impressions derived from both eyes, and that which is derived from either eye singly; the latter, moreover, harmonizing-with and being strengthened-by our recollection of the object as we have seen it before, or (if it be new to us) by our notion of its natural appearance.

619. The *persistence*, during a certain interval, *of impressions made upon the retina*, gives-rise to a number of curious visual phenomena, which can be here only briefly adverted-to. The prolongation of the impression will be governed, in part, by its previous duration: thus, when we rapidly move an ignited point through a circle, the impression itself is momentary, and remains but for a short period; whilst, if we have been for some time looking at a window, and then close our eyes, the impression of the dark bars traversing the illuminated space is preserved for several seconds. One of the results of this persistence is the combination, into a single image, of two or more objects presented to the eye in successive movements; but these must be of a kind which can be united, otherwise a confused picture is produced. Thus in a little toy, called the Thaumatrope, which was introduced some years ago, the two objects were painted on the opposite sides of a card,—a bird, for instance, on one, and a cage on the other; and, when the card was made (by twisting a pair of strings) to revolve about one of its diameters, in such a manner as to be alternately presenting the two sides

to the eye at minute intervals, the two pictures were blended, the bird being seen in the cage. A far more curious illusion, however, was that first brought into notice by Prof. Faraday; who showed that, if two toothed wheels, placed one behind the other, be made to revolve with equal velocity, a stationary spectrum will be seen; whilst if one be made to revolve more rapidly than the other, or the number of teeth be different, the spectrum also will revolve. The same takes-place when a single wheel is made to revolve before a mirror, the wheel and its image answering the purpose of the two wheels in the former case. On this principle, a number of very ingenious toys have been constructed; in some of these, the same figure or object is seen in a variety of positions; and the successive impressions, passing rapidly before the eye, give-rise by their combination to the idea that the object is itself moving through these positions.*—It is interesting to remark, moreover, that when the eye has been for some time contemplating an object in motion, and is then directed towards stationary objects, *these* appear for a short time to have a like movement. Any rail-road traveller may try this simple experiment, by first looking at the hedges, &c. which he is rapidly passing, and then at some part of the interior of the carriage itself, especially one which presents a series of parallel lines. But when the impression of movement has been of longer duration, its effects are less transient; thus, a person who has been for some time on board ship, sees the floors, walls, and ceilings of his apartments on shore in a state of continual up-and-down motion, even for some days after he has landed. This would seem to be rather a *sensorial* than a *retinal* phenomenon.

620. When the Retina has been exposed for some time to a strong impression of some particular kind, it seems less susceptible of feebler impressions of the same kind. Thus, if we look at any brightly luminous object, and then turn our eyes on a sheet of white paper, we shall perceive a dark spot upon it; the portion of the retina which had been affected by the bright image, not being able to receive an impression from the fainter rays reflected by the paper. The dark spectrum does not at once disappear, but assumes different colours in succession,—these being expressions of the states through which the retina is passing, in its transition to the natural condition. If the eye has received a strong impression from a *coloured* object, the spectrum exhibits the *complementary* colour;† thus, if the eye be fixed for any length of time upon a bright red spot on a white ground, and be then suddenly turned so as to

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* A very beautiful 'philosophical toy' was shown to the Author some years since, by its inventor, Mr. Roberts, the celebrated machinist of Manchester; consisting in an apparatus by which it was made possible to read words printed on a card, although the card itself was made to revolve on its axis even 40,000 times in a minute. The principle of its construction was simply this,—that the eye caught a succession of glimpses of the card, through a narrow slit before which a disk with a single corresponding perforation was made to revolve; the rate of movement of this disk being so adjusted to that of the card, that whenever the eye caught sight of the latter, it was *momentarily* in the same position, so that, by the succession of transient impressions thus made upon the retina, the words printed on the card could be distinctly read.

† By the 'complementary' colour is meant that which would be required to make white or colourless light, when mixed with the original: thus red is the complement of green (which may be made by mixing yellow and blue); blue is the complement of orange (red and yellow); and yellow of purple (red and blue); and *vice versâ* in all instances.

rest upon the white surface, we see a spectrum of a green colour.—The same explanation applies to the curious phenomenon of 'coloured shadows.' It may not unfrequently be observed at sunset, that, when the light of the sun acquires a bright orange colour from the clouds through which it passes, the shadows cast by it have a blue tint. Again, in a room with red curtains, the light which passes through these produces green shadows. In both instances, a strong impression of one colour is made on the general surface of the retina; and at any particular spots, therefore, at which the light is colourless but very faint, that colour is not perceived, its complement only being visible. The correctness of this explanation is proved by the fact, that, if the shadow be viewed through a tube, in such a manner that the coloured ground is excluded, it seems like an ordinary shadow. It is not unlikely that, as Müller suggests, the predominant action of one colour on the retina disturbs (as it were) the equilibrium of its condition, and excites in it a tendency to the development of a state corresponding to that which is produced by the impression of the complementary colour; for the latter is perceived, as he remarks, even where it does not exist; as when the eye, after receiving a strong impression from a coloured spot, and being directed upon a completely dark surface or into a dark cavity, still perceives the spectrum. This change, indeed, extends beyond the spot on which the impression is made (§ 622); for, as is well known to Artists, the sensory impression produced by any colour is greatly affected by neighbouring hues. Thus, if four strips of coloured paper, or any other fabric, A, B, C, D,—two of them, A, B, of one colour (*e.g.* red), and the other two, C, D, of some different colour (*e.g.* blue),—be laid side-by-side at intervals of about half an inch, the hues of the two central strips B, C, will be decidedly modified by each other's proximity, each approximating to the hue of the complementary colour of the other; so that instead of

A	B	C	D
red	red	blue	blue.

we shall see

A	B	C	D
red	orange-red	greenish-blue	blue.

621. Upon the properties of the Eye in regard to Colour, are founded the laws of harmonious colouring, which have an obvious analogy with those of musical harmony. All complementary colours have an agreeable effect when judiciously disposed in combination; and all bright colours, which are not complementary, have a disagreeable effect, if they are predominant: this is especially the case in regard to the simple colours, strong combinations of any two of which, without any colour that is complementary to either of them, are extremely offensive. Painters who are ignorant of these laws, introduce a large quantity of dull grey into their pictures, in order to diminish the glaring effects which they would otherwise produce; but this benefit is obtained by a sacrifice of the vividness and force, which may be secured in combination with the richest harmony, by a proper attention to physiological principles.*—Some

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* This subject has been most carefully and elaborately investigated by M. Chevreul; whose recent Treatise on Colours has almost exhausted the inquiry into the mode in

persons whose visual powers are excellent in every other respect, are more or less deficient in the power of discriminating *colours*. This defect (which is now commonly known as 'Daltonism,' from the name of the distinguished philosopher who was himself the subject of it) may be so complete, that nothing can be perceived save different degrees of light and shadow; more commonly, however, it exists only with regard to particular colours, especially such as have a complementary relation to one another, so that persons thus affected are unable (*e.g.*) to distinguish ripe cherries among the leaves of the tree, save by their form; whilst in some individuals it does no more than confuse colours that are nearly related, such as green and blue, especially when they are seen by artificial light. Whether its seat be in the nervous apparatus of the Eye, or in the Sensorium, cannot be positively determined; but the latter seems the most probable supposition.*

622. The impressions made by luminous objects upon the Retina are not precisely confined to the spots upon which their rays impinge, but extend themselves to a greater or less distance around; which phenomenon has been termed *irradiation*. Thus if we make a circular white spot upon a black ground, and a black spot of precisely the same dimensions upon a white ground, the former will seem to be considerably larger than the latter; apparently because the excitation of the retina by the luminous impression tends to spread itself in each case over the adjacent non-excited space. Hence it is that we are able to distinguish any small magnitudes, such as letters or the lines of a diagram, at a much greater distance when they are marked in white on a black ground, than when inscribed in black upon a white ground. Another curious case of the same kind has been noticed by Sir D. Brewster.† "If we shut one eye, and direct the other to any fixed point, such as the head of a pin, we shall see indistinctly all other objects within the sphere of vision. Let one of these objects thus indistinctly seen, be a strip of white paper or a pen lying on a green cloth. Then, after a short time, the strip of paper, or the pen, will disappear altogether, as if it were entirely removed; the impression of the green cloth upon the surrounding parts of the retina, extending over that part of it which the image of the pen occupied. In a short time the vanished image will re-appear, and again vanish; when both eyes are open, the very same effect takes place, but not so readily as with one eye. If the object seen indistinctly is a black stripe on a white ground, it will vanish in a similar manner. When the object seen obliquely is luminous, such as a candle, it will never vanish entirely, unless its light is much weakened by being placed at a great distance; but it swells and contracts, and is encircled by a nebulous halo."

623. The power of receiving and transmitting visual impressions is by no means uniformly diffused over the entire Retina. In the whole field

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which the Visual sense of Man is affected by them. For a general view of the nature and attributes of Light, see Art. 'Light,' by Sir J. Herschel, in the last edition of the "Encyclopædia Metropolitana."

* See especially the Memoir of Prof. Seebeck, in "Poggendorff's Annalen," band xlii. (1837); that of Prof. Wartmann in "Taylor's Scientific Memoirs," vol. iv. p. 156; Mr. Pole's case recorded in the "Proceedings of the Royal Society," 1856-57, vol. viii. p. 172, and the interesting commentary upon it by Sir J. Herschel, in idem, vol. x. p. 72.

† 'Treatise on Optics,' in Lardner's "Cyclopædia," p. 296.

of vision which at any time lies before us, we only see with perfect distinctness that part to which the axes of our eyes are directed, and of which the image, therefore, is formed upon the 'yellow spot' (§ 606). Nevertheless we have a sufficiently distinct perception of the remainder of the field, to enable us to judge of the relations of the objects which are distinctly seen to those which surround them; and the mobility of our eyes enables us, under the guidance of our visual sense (§ 529), to direct the most sensitive spot of the retina to every part of the field in succession, not only without effort, but even almost without the consciousness that we are doing so.—Generally speaking, the indistinctness of vision for objects seen out of the axis of the eye, increases with the distance of their images from the central point; or, in other words, the impressibility of the several parts of the retina diminishes, according to their distance from the 'yellow spot.' For a small space around it, however, the vision is tolerably accurate, and the extent of this circle of clear 'indirect vision,' as it is termed, varies in different people; Volkmann, for instance, can read an entire word by the light of a single electrical spark, and must therefore have instantaneously a direct and perfect perception of every part of it, whilst by others only a letter or two can be distinguished. It appears also from the experiments of Aubert and Förster,* and of Heymann,† that when the Eye is accommodated for near objects, the limits of clear lateral perception are increased, or at least that the perceptibility of that circle is intensified; so that of two objects which throw images of equal size on the Retina, the smaller and more approximated one is distinctly perceived at a greater distance from the yellow spot than the larger and more distant object. But there is one part of the retinal surface, namely, the seat of entrance of the Optic Nerve, which is remarkable for its imperfect receptivity; as is shown by the following experiment. Let two black spots be made upon a piece of paper, about four or five inches apart; then let the left eye be closed, and the right eye be strongly fixed upon the left-hand spot; if the paper be then moved backwards and forwards, so as to change its distance from the eye, a point will be found at which the right-hand spot is no longer visible, though it is clearly seen when the paper is brought nearer or removed further. In this position of the eye and the object, the rays from the right-hand spot cross to the nasal side of the globe, and fall upon the point of the retina which has just been mentioned. If the same experiment be tried with candles, the image will not entirely disappear, but will become a cloudy mass of light. It is not correct to say, as is sometimes done, that the retina is not impressible by light at this point; since, if such were the case, we should see a dark spot in our field of view whenever we use only one eye, which is not the case. The fact seems rather to be, that this portion of the retina is very inferior to the surrounding parts in its receptivity for luminous impressions; whilst, on the other hand, there is an unusual tendency to the extension of *their* condition to it by 'irradiation' (§ 622); so that, in the experiment just described, if the black spots be made upon a coloured ground, this colour will take the place of the spot which disappears.

624. The impression made by rays of light upon the Retina may be

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* "Archiv f. Ophthalmol.," band iii. p. 1.

† "Acta Academ. C.L. C.G. Naturæ Curiosorum," Dresden, 1864.

to a certain extent imitated by other physical agencies (§ 582), which thus give rise to various *subjective* visual phenomena. Advantage has recently been taken by Dr. Serre,* of the power of mechanical pressure to produce luminous spectra, for the investigation of the 'law of visual direction' (§ 610); and the results which he has obtained are of very great interest. When any part of the globe of the eye is compressed (the experimenter being in a completely-darkened room), a luminous figure is seen to be projected in the direction opposite to the spot pressed-upon. Its form varies according to that of the compressing body, and to the degree in which the retina is affected by it. Thus if the pressure be made by the point of the finger, or by any other circular surface, upon a part of the globe over the interior of which the retina is continuous, the spectrum, or *phosphène* (as it is termed by Dr. Serre), is also circular; if the compressing body, on the other hand, be square at its extremity, the 'phosphène' is also square; and if it be triangular, the 'phosphène' is triangular too. But if the pressure be made near the anterior edge of the retina (which is what most commonly happens, unless the most favourable situation be designedly chosen), the figure of the 'phosphène' is incomplete; and the degree of its deficiency corresponds with the proportion of the area of compression that does not lie-over the retinal expansion. Hence there can be no hesitation in regarding the production of this spectrum as the immediate result of the affection of the sensorium by the pressure on the retina; and as it seems to our perceptive consciousness to have a distinct objective existence, and as its position bears a constant and definite relation to that of the portion of the retina on which the impression is made, it seems obvious that any such affection of the retina not only immediately suggests to our minds the notion of an external objective cause of the impression, but also indicates to our consciousness the *direction* of the object.—But further, besides the principal 'phosphène,' another, of smaller dimensions, is usually to be seen, in a direction nearly the same as that on which the pressure is made; this is the result of the transmission of the pressure to the *opposite* side of the globe, by an alteration of its figure and of the position of its contents, which corresponds to the fracture of the skull by *contre-coup*. The form of this smaller or secondary 'phosphène' is not affected by the cause which sometimes renders the larger or primary spectrum incomplete; since, as we cannot anywhere apply pressure to the living Human eye, save on some part of its anterior hemisphere, the 'contre-coup' will always take-place at the opposite spot in the posterior hemisphere, over which the retina is continuous, save at the entrance of the optic nerve. By an extensive series of observations upon the relation of the positions of the primary and secondary 'phosphènes,' both to each other and to the seat of compression, Dr. Serre has deduced the important conclusion, that the lines joining the imaginary spectra and the spots of the retina from whose affection they respectively proceed, pass through a common 'centre of direction,' whose position is in the middle of the crystalline lens. And hence it seems to be a legitimate conclusion, that our sense of the relative directions of external objects is derived from a kind of mental projection of each point of the retinal image, in the line which joins it to this 'centre of direction.'

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* See his "Essai sur les Phosphènes," Paris, 1853.

625. Another very curious *subjective* phenomenon of Vision, is the representation which, under particular circumstances, we may mentally obtain of the retina itself; as in the following experiment, first devised by Purkinje, and known by his name. "If in a room otherwise dark, a lighted candle be moved to and fro, or in a circle, at a distance of six inches before the eyes, we perceive, after a short time, a dark arborescent figure ramifying over the whole field of vision; this appearance is produced by the vasa centralia distributed over the retina, or by the parts of the retina covered by those vessels. There are, properly speaking, two arborescent figures, the trunks of which are not coincident, but on the contrary arise in the right and left divisions of the field, and immediately take opposite directions. One trunk belongs to each eye, but their branches intersect each other in the common field of vision. The explanation of this phenomenon is as follows:—By the movement of the candle to and fro, the light is made to act on the whole extent of the retina, and all the parts of the membrane which are not immediately covered by the vasa centralia are feebly illuminated; those parts, on the contrary, which are covered with those vessels, cannot be acted-on by the light, and are perceived, therefore, as dark arborescent figures. These figures appear to lie before the eye, and to be suspended in the field of vision;"* and as the vessels appear magnified, and display a remarkable parallactic gliding movement over the visual field, data are afforded by which H. Muller has calculated that the true percipient surface of the retina must be situated at a certain distance from the vessels, corresponding in fact with the bacillar layer.† We have thus another demonstration of the fact, that, in ordinary Vision, the immediate object of our sensation is a certain condition of the retina, which is excited by the formation of a luminous image.

626. The Visual power is susceptible of extraordinary improvement, through the habitual direction of our *attention* to the effects produced upon our consciousness by the impressions transmitted to the Sensorium from the Eye; and this improvement may take place, either in regard to the quickness and readiness with which objects generally are perceived, or in the faculty of discriminating the slightest differences in form, shade, colour, &c., or of discerning bodies of extreme minuteness. In regard to all these points it may be noticed that the habit of attention to any particular class of objects, sharpens the discriminating power for that class alone; and that it is usually rather the mental than the corporeal vision which undergoes improvement. Thus the Seaman who makes-out the 'loom of the land,' where the landsman can discern nothing but an indefinite haze above the horizon, or who can distinguish the size, rig, and course of a vessel, which the landsman can but just see as a formless speck, does so in virtue of the aptitude of his mind for receiving suggestions from minute indications such as pass unnoticed by those who have not been accustomed to form their ideas upon the same kind of experiences. And the Microscopist, who is constantly on the outlook for the various forms

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* Müller's "Elements of Physiology" (Baly's Translation), p. 1163.

† For the explanation of various other entoptical phenomena, see James Jago, B.A., in "Proceedings of the Royal Society," vol. viii. p. 603. He observes that the long beams of light which issue from flames regarded with 'winking eyes' proceed from little bars of fluid along the margins of the lids.

of organic structure with which his mind is familiar, discerns these without difficulty or hesitation, where an ordinary observer sees nothing but a confused jumble of tissue. Extremely slight variations in the relative illumination of two objects can readily be discerned. According to Arago* the difference can be perceived when it amounts to no more than about 1-64th, according to Volkmann when it is from 1-60th to 1-100th, to Steinheil 1-38th, and to Masson 1-120th. Aubert† has shown that these variations in the results obtained by different observers are probably due to their having employed different amounts of illumination; since the perception of slight variations is much greater, within certain limits, with bright than with feeble illuminating powers.—It is interesting to observe that the power of descrying objects at vast distances appears to be hereditarily possessed by two races of men, the Mongols of Northern Asia, and the Hottentots of Southern Africa, both of which habitually dwell on vast plains that seem to stretch without limit in every direction. It seems probable that this power was in the first instance acquired by habit in each case; and that, as frequently happens with acquired peculiarities which are kept-up by constant use in successive generations,‡ it has become fixedly hereditary.

6. *Sense of Hearing.*

627. In the Ear, as in the Eye, the impressions made upon the sensory nerve are not at once produced by the body which originates the sensation; but they are propagated to it, through a medium capable of transmitting them. We obviously take cognizance by the mind, therefore, not of the sonorous object, but of the condition of the auditory nerve; and all the ideas we form of sounds, as to their nature, intensity, direction, &c., must be based upon the changes which they produce in it. The complex contrivances which we meet-with in the organ of Hearing among higher animals, are evidently intended to give them greater power of discriminating sounds than is possessed by the lower tribes; in which last it is reduced to a form so simple that it may be questioned whether they can be said to possess an organ of *hearing*, if by this term we imply anything more than the mere consciousness of sonorous vibrations.—There is a considerable difference, however, between the Eye and the Ear, in regard to the special purposes for which they are respectively adapted. In the former we have seen that the whole object of the instrument is to direct the rays of light received by it, in such a manner as to occasion them to fall upon the expansion of the optic nerve in similar relative positions, and with corresponding proportional intensities, to those which they possessed when issuing from the object. We have no reason to believe anything of this kind to be the purpose of the Ear; indeed it would be inconsistent with the laws of the propagation of sound. Sonorous vibrations having the most various directions, and the most unequal rates of succession, are transmitted by all media without modification, however numerous their lines of intersection; and wherever these undulations fall

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* "Astronomie," vol. i. p. 194.

† "Physiologie der Netzhaut," 1864.

‡ See "Princ. of Comp. Physiol.," § 620.

upon the auditory nerve, they must cause the sensation of corresponding sounds. Still it is probable that some portions of the complex organ of hearing, in Man and in the higher animals, are more adapted than others to receive impressions of a particular character; and that thus we may be especially informed of the direction of a sound by one part of the organ, of its musical tone by another, and of some other of its qualities by a third.

628. A single impulse communicated to the Auditory nerve through an appropriate apparatus, seems to be sufficient to excite the momentary sensation of *sound;* but most frequently a series of such impulses is concerned, there being but few sounds which do not partake, in a greater or less degree, of the character of a *tone.* Any continuous sound or tone is dependent upon a succession of impulses; and its acuteness or depth is governed by the rapidity with which these succeed one another. It is not difficult to ascertain by experiment, what number of such impulses or undulations are required to give every tone which the ear can appreciate. Thus, if a circular plate, with a number of apertures at regular intervals, be made to revolve over the top of a pipe through which air is propelled, a succession of short *puffs* will be allowed to issue from this; and, if the revolution be sufficiently rapid, these impulses will unite into a definite tone. In the same manner, if a spring be fixed near the edge of a revolving toothed wheel, in such a manner as to be caught by every tooth as it passes, a succession of *clicks* will be heard; and these too, if the revolution of the wheel be sufficiently rapid, will produce a tone. The number of apertures in the plate which pass the orifice of the pipe in a given time, or the number of teeth which pass the spring, being known, it is easy to see that this must be the number of impulses required to produce the given tone. Each impulse produces a double vibration, forwards and backwards (as is seen when a string is put in vibration, by pulling it out of the straight line); hence the number of single vibrations is always double that of the impulses.—The maximum and minimum of the intervals of successive pulses, still appreciable by the ear as determinate musical sounds, have been determined by M. Despretz.* According to this observer the number of vibrations required to produce an appreciable musical sound, in persons endowed with an acute sense of hearing, may vary from 16 for the lowest, to 73,000 for the highest note. From some observations of Dr. Wollaston, it seems probable that the ears of different individuals are differently constituted in this respect; some not being able to hear very acute tones produced by Insects, or even Birds, which are distinctly audible to others. Again, the sound resulting from 16 impulses per second, is not, as has been usually supposed, the lowest appreciable note; on the contrary, M. Savart has succeeded in rendering tones distinguishable, though they can scarcely be termed musical, which are produced by only 7 or 8 impulses in a second; and continuous sounds of a still deeper tone could be heard, if the individual pulses were sufficiently prolonged. In regard, however, to the precise time during which a sonorous impression remains upon the ear, it is difficult to procure exact information, since it departs more gradually than do visual impressions from the eye. This is certain, however,—that it is much longer than the interval between the successive pulses in the production of tones;

* "Comptes Rendus," tom. xx. p. 1214.

since it was found by M. Savart, that one or even several teeth might be removed from the toothed wheel, without a perceptible break in its sound,—showing that, when the tone was once established, the impression of it remained during an intermission of some length.

629. A very recondite investigation into the theory of Acoustics, and especially into the conditions on which the distinct qualities of musical tones depend, has recently been undertaken by Helmholtz.* It is possible, he observes, to produce sounds consisting of only a single primary or *fundamental note;* the fundamental note of a sonorous body being the lowest tone which it yields when the whole of it is in vibration together; but in by far the greater number of instances, sounds however produced, and whether musical in their character or not, are compounded of the fundamental note and a number of secondary collateral or harmonic notes; and the peculiar quality or *timbre* of particular instruments appears to be determined by a variation in the mode of grouping of the secondary sounds. Each such group Helmholtz designates a "sound colour." In a series of experiments upon the vowel sounds, *a*, *e*, *i*, *o*, and *u*, he has remarked that we distinguish them from one another† by the harmonic sounds which accompany the chief or fundamental note, and he endeavours to render this evident by the following experiments. He terms the fundamental note the first (1), whilst the harmonics (2, 3, 4, 5, 6, &c.) are notes produced by two, three, four, five, or six times the number of vibrations of the fundamental note. Thus, taking the middle C of the piano as the fundamental note, the harmonics will be $\underset{2}{C_2}$ (octave) $\underset{3}{G}$, $\underset{4}{C_3}$ (double octave) $\underset{5}{E_3}$ $\underset{6}{G_3}$, &c. Now if the vowel *a* be sung close to a piano with the damper up, not only will the wire corresponding to the fundamental note be thrown into vibration, but also the wires corresponding to the 3rd and 5th harmonics, or those vibrating three times and five times as often as the fundamental note, and also more feebly the 2nd, 4th, and 7th harmonic notes. When the vowel *o* is sung, the 3rd harmonic note vibrates somewhat more weakly than when *a* is sung; the 2nd and 5th harmonics very weakly. With *u* the fundamental note vibrates almost alone; the 3rd harmonic very feebly. With *e* the 2nd harmonic wire is thrown into powerful vibration, but the higher harmonics are scarcely produced. With *i*, as with *u*, it is difficult to pronounce it loudly enough to excite vibrations in any but the fundamental note; the 2nd and 3rd harmonics, however, appear to aid in determining the clear character of the note, and slight vibrations may be observed in the 5th harmonic. The wires of the piano in these instances may be said to analyze the vocal sound into its secondary elements or partial notes; and Helmholtz has shown that the same result may be attained by placing in connection with the ear a series of glass vessels, producing by their vibration harmonic notes, and ascertaining with which note or kind of note they resonate most powerfully. In another series of experiments, instead of analyzing the vocal sounds as above mentioned, Helmholtz endeavoured to produce them *synthetically*, by accompanying a given fundamental note with its several harmonics. This

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* "Die Lehre von den Ton-empfindungen als physiologische Grundlage für die Theorie der Musik," Braunschweig, 1862.

† It must be borne in mind that the *German* vowels are here implied.

was accomplished by a system of tuning-forks, arranged in harmonic series, which could be thrown into vibration at will in various order. Thus the fundamental note of the first tuning-fork, resembling the vowel *u*, the vowel sound or musical colour *o* was produced if the harmonics 2 were powerfully, and 3 and 4 were weakly sounded; *e* was produced by the 3rd octave resonating powerfully with the fundamental note, the 2 harmonic note moderately, and the 4 and 5 harmonics feebly, and so on for the other vowel sounds.—The power which we possess of distinguishing the characters belonging to similar notes produced by different instruments, appears, therefore, to be due to a kind of analysis being performed by the ear, similar to that effected by the wires of the piano; and we shall see that it is not unreasonable to attribute this function especially to the branches of the auditory nerve distributed upon the lamina spiralis of the cochlea.

630. The essential part of an Organ of Hearing is obviously a nerve endowed with the peculiar property of receiving sonorous undulations, and of transmitting their effects to the Sensorium. This nerve is spread-out over the surface of a delicate-membrane which lines the Vestibule and its prolongations; and this membrane encloses a fluid, which is the medium whereby the sonorous vibrations received through the external ear are communicated to the nerve. We learn from an examination of the comparative structure of the auditory apparatus in the lower animals, and from the study of its development in the higher, that the part which, being most constantly present, and being also the earliest in its development, may be considered as the most essential, is the simple *Vestibular* cavity; which exists where there are no vestiges either of Semicircular Canals, of Cochlea, or of Tympanic apparatus. Such a condition presents itself in some of the higher Invertebrata and in the lowest Fishes; but as we ascend the Vertebrated series, we find the semicircular canals growing out (as it were) of the Vestibule in Fishes, a tympanic apparatus superadded in Reptiles, and a Cochlea first acquiring a more than rudimentary development in the class of Birds, although only presenting in Mammalia that characteristic form from which it derives its name.* Of the mode in which the ultimate subdivisions of the Auditory nerve are distributed upon the lining membrane of the labyrinth, it does not yet seem possible to give a certain account; for although Wagner and others have represented them as terminating in free loops, yet more careful observation has rendered this doubtful; and the general analogy between the simpler forms of the auditory and of the visual apparatus, as well as the close correspondence which exists between them in the history of their development (the organ of hearing, like the eye, being budded-off from its sensory ganglion), seem to indicate that the peripheral expansion of the auditory nerve might be expected to have a structure analogous to that of the retina. The structure of the cochlea has recently been materially elucidated by the extraordinarily minute and delicate dissections of Corti,† Schultze, Kölliker, and others. The canal of the cochlea, according to

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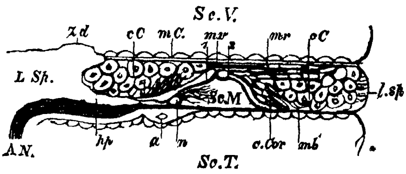
* For a more detailed sketch of the Comparative Anatomy of the Organ of Hearing, see the Author's "Principles of Comparative Physiology," §§ 711–714.

† See his Memoir in Kölliker and Siebold's "Zeitschrift für wissenschaftliche Zoologie," 1851, band iii. heft 1; also Prof. Kölliker's "Mikroskopische Anatomie," band ii. § 289, and his "Manual of Microscopic Anatomy," 1860.

Kölliker, is filled with the fluid of the labyrinth, and contains not only the two well-known cavities, the Scala Tympani and Scala Vestibuli (*Sc. V.* and *Sc. T.*, Fig. 139), but also a third narrower space which he proposes to call the Scala Media (*Sc. M.*). This is situated in great measure within the Lamina Spiralis, and contains the ultimate terminations of the cochlear branches of the auditory nerve. The lamina spiralis consists of an inner bony and an outer membranous portion; the former terminates by a grooved edge, the upper margin of the groove (*Z. d.*) being termed the Zona Denticulata, in consequence of its presenting a series of well-marked teeth, the lower margin (*h. p.*) the Habenula Perforata. From each of these a layer of periosteum is continued to the opposite wall of the cochlea, completing the septum between the Scala Tympani and Scala Vestibuli. The upper layer is termed the Membrane of Corti (*m. C.*), the lower one the Membrana Basilaris (*m. b.*). Connected with the habenula perforata, and lying in the scala media, or space between the two membranes, are certain structures termed the Rods of Corti. These (1 and 2) form an angle with one another resembling the gable end of a house, and appear to be connected above by a delicate membrane, the Membrana Velamentosa. The space between the groove of the bony lamina spiralis and the first set of the rods of Corti, and the space between the outer wall of the cochlea and the second set of the rods of Corti, are filled with large nucleated cells (*c. C.*), the cells of Claudius. The interval between the two sets of rods and the membrana basilaris (*Sc. M.*) is probably filled with fluid. The branches of the auditory nerve lie on the under surface of the lamina spiralis, beneath the habenula perforata, through which they pass by many small openings, and (though there is much difficulty in following them at this part) apparently terminate by free and extremely delicate extremities amongst the cells of Claudius, and in the fluid of the scala media. The accompanying diagram will give some idea of the relations of these delicate parts as they appear to be determined by the most recent investigations.*

FIG. 139.



L. Sp., Lamina Spiralis, dividing *Sc. V.*, the Scala Vestibuli, from *Sc. T.*, the Scala Tympani, and presenting at its edge *Z. d.*, the Zona denticulata and *h. p.*, the Habenula perforata. *m. C*, the Membrane of Corti, covered with epithelium prolonged from the Zona denticulata. *m. b.*, membrana basilaris prolonged from the habenula perforata, and also covered with epithelium. *c. C.*, cells of Claudius. 1, Rod of Corti of the first order or set. 2, Rod of Corti of the second order. Between these and the membrana basilaris is a triangular space, *Sc. M.*, the Scala Media, into which the free extremities of the auditory nerves project. *n*, a well-defined nucleus. *a.*, spiral vessel. *m. r.*, membrana reticularis, *l sp*, ligamentum spirale. *c. Cor.*, cells of Corti. *m. v.*, membrana velamentosa.

631. In order to gain any definite idea of the uses of different parts o the Ear, it is necessary to bear in mind that sounds may be propagated amongst solid or fluid bodies in three ways; by *reciprocation*, by *resonance*, and by *conduction*.—1. Vibrations of *reciprocation* are excited i a sounding body, when it is capable of yielding a musical tone of definit pitch, and another body of the same pitch is made to sound near i Thus if two strings of the same length and tension be placed alongside c

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* See Fick, "Anatomie und Physiologie der Sinnes Organe," 1862, p. 122.

each other, and one of them be sounded with a violin-bow, the other will be thrown into reciprocal vibration; or if the same tone be produced near the string in any other manner, as by a flute or a tuning-fork, the same effect will result.—2. Vibrations of *resonance* are of somewhat the same character; but they occur when a sounding body is placed in connection with any other, of which one or more parts may be thrown into reciprocal vibration; even though the tone of the whole be different, or it be not capable of producing a definite tone at all. This is the case, for example, when a tuning-fork in vibration is placed upon a sound-board; for even though the whole board have no definite fundamental note, it will divide itself into a number of parts, which will reciprocate the original sound, so as greatly to increase its intensity; and the same sound-board will act equally well for tuning-forks of several different degrees of pitch. When a smaller body is used for resonance, however, it is essential that there should be a relation between its fundamental note and that of the sonorous body; otherwise no distinct resonance is produced. Thus, if a tuning-fork in vibration be held over a column of air in a tube, of such a length that the same note would be given by its vibration, its sound will be reciprocated. And if it be held over a pipe, the column of air in which is a multiple of this, the column will divide itself into that number of shorter parts, each of which will reciprocate the original sound, and the total action will be one of resonance. But if the length of the pipe bear no such correspondence with the note sounded by the tuning-fork, no resonance is given by the column of air it contains.—3. Vibrations of *conduction* are the only ones by which sounds can strictly be said to be propagated: these are distinguishable into various kinds, into which it is not requisite here to inquire. It should be remarked, however, that all media, fluid, liquid, or solid, are capable of transmitting sound in this manner; a vacuum being the only space through which it cannot pass. The transmission is usually much more rapid through solid bodies, than through liquid; and through liquid, than through gaseous. The greatest diminution in the intensity of sound is usually perceived, when a change takes-place in the medium through which it is propagated, especially from the aeriform to the liquid.

632. The detailed application of these principles has been most elaborately worked-out by Prof. Müller; and the following statement is little more than an abstract of the results of his experimental investigations; of which the first series bears specially on the case of those animals, which, living immersed in water, receive the sonorous undulations through that medium. The labyrinth of such as possess a distinct organ of hearing, is either entirely enclosed within the bones of the head, as in the Cephalopoda and in the Cyclostome and Osseous Fishes; or, its cavity being prolonged to the surface of the body, it is there brought into communication with the conducting medium by means of a membrane, besides receiving the vibrations through the medium of the solids of the body, as is the case in Cartilaginous Fishes and Crustacea:—I. Sonorous vibrations, excited in water, are imparted with considerable intensity to solid bodies.—II. Sonorous vibrations of solid bodies are communicated with greater intensity to other solid bodies brought in contact with them, than to water; but with much greater intensity to water, than to atmospheric air.—III. Sonorous vibrations are communicated from air to

water with great difficulty, this difficulty very much exceeding that with which they are propagated from one part of the air to another; but their transition from air to water is much facilitated by the intervention of a membrane extended between them.—IV. Sonorous vibrations are not only imparted from water to solid bodies with definite surfaces which are in contact with the water, but are also returned with increased intensity by these bodies to the water; so that the sound is heard loudly in the vicinity of those bodies, in situations where, if it had its origin in the conducting power of the water alone, it would be faint.—V. Sonorous undulations, propagated through water, are partially reflected by the surfaces of solid bodies.—VI. Thin membranes conduct sound in water without any loss of its intensity, whether they be tense or lax.—VII. When sonorous vibrations are communicated from water, to air inclosed in membranes or solid bodies, a considerable increase in the intensity of the sound is produced, by the resonance of the air thus circumscribed.—VIII. A body of air inclosed in a membrane, and surrounded by water, also increases the intensity of the sound by resonance, when the sonorous undulations are communicated to it by a solid body.

633. Animals living in air are nearly always provided with an opening into the Vestibule, the *fenestra ovalis*, covered by a thin membrane; and generally with a *Tympanic apparatus* also. The following experimental results bear upon the manner in which the Ear of such animals is affected by sound:—IX. Sonorous undulations, in passing from air directly into water, suffer a considerable diminution in their strength; while, on the contrary, if a tense membrane exist between the air and the water, the sonorous undulations are communicated from the former to the latter medium with great intensity.—X. The sonorous vibrations are also communicated without any perceptible loss of intensity from the air to the water, when, to the membrane forming the medium of communication, there is attached a short solid body, which occupies the greater part of its surface, and is alone in contact with the water.—XI. A small solid body, fixed in an opening by means of a border of membrane, so as to be moveable, communicates sonorous vibrations from air on one side to water or the fluid of the labyrinth on the other, much better than solid media not so constructed. But the propagation of sound to the fluid is rendered much more perfect, if the solid conductor, thus occupying the opening, is by its other end fixed to the middle of the tense membrane which has atmospheric air on both sides.—The fact stated in IX. is evidently one of great importance in the physiology of hearing; and fully explains the nature of the process in those animals which receive the sonorous vibrations through air, but which have no tympanic apparatus. In X. we have the elucidation of the action of the fenestra ovalis, and of the moveable plate of the stapes which occupies it, in animals living in air but destitute of tympanic apparatus; this is naturally the case in many Amphibia; and it may happen as the result of disease in the Human subject. In XI. we have a very interesting demonstration of the purpose and action of the tympanum, in the more perfect forms of the auditory apparatus.—We are now prepared to inquire, in somewhat more of detail, into the actions of the different parts of this apparatus; and it will be better to commence with those of the *Middle* and *Internal Ear*, the accessory organs being afterwards considered.

634. The *Membrana Tympani* consists of three layers; an *external* one continuous with the cutis of the external meatus, and consisting of dermoid tissue with a covering of epidermic cells; an *internal*, which is extremely thin, continuous in like manner with the mucous membrane lining the tympanic cavity, and also composed of dermoid tissue and epithelium; and a *middle* layer, which, according to Mr. Toynbee,* may be separated into two distinct laminæ whose fibres run in contrary directions, those of the external layer (which is the stronger of the two) *radiating* from the malleus towards the peripheral ring to which they are attached, whilst those of the internal are *annular.* The fibres of which these laminæ are composed do not appear to be muscular; nor do they present the longitudinal parallel wavy lines characteristic of ordinary fibrous membranes; and they are rendered opaque by acetic acid. Hence, although those laminæ appear to be derived, the external from the periosteum of the meatus, and the internal from that of the tympanic cavity, they differ from it in elementary structure, and seem to have more in common with elastic tissue. Mr. Toynbee points out the existence of a tubular ligament, enclosing the tendon of the tensor tympani muscle; and considers that the membrane is maintained by this ligament in a state of moderate tension, the assistance of the muscle being only required to augment this.—The function of the *Membrana Tympani* seems obviously to be the reception of sonorous undulations from the air, in such a manner that it may be thrown by them into a reciprocal vibration, which is communicated to the chain of bones. In its usual state, this membrane is scarcely on the stretch; and this is found by experiment to be, for a small membrane, the best condition for the propagation of ordinary undulations. This is easily rendered sensible in one's own person; for an increased tension may be given to the membrana tympani, either by holding the breath and forcing air into the Eustachian tube, so as to distend it from within, or by exhausting the cavity, so as to cause the external air to make increased pressure upon it; and in either case, the hearing is immediately found to become indistinct. It is observed, however, that grave and acute sounds are not equally affected by this action; for the experimenter renders himself deaf to grave sounds, whilst acute sounds are heard even more distinctly than before. This fact is readily understood, by referring to the laws of Acoustics already mentioned. The greater the tension to which the membrana tympani is subjected, the more acute will be its fundamental tone; and as no proper reciprocation can take-place in it to any sound *lower* than its fundamental tone, its power of repeating perfectly the vibrations proper to the deeper notes will diminish. The nearer a sound approaches to the fundamental note proper to the tense membrane, the more distinctly will it be heard. On the other hand, when the membrane is in its naturally-relaxed condition, its fundamental note is very low, and it is capable of repeating a much greater variety of sounds; for, when it receives undulations of a higher tone than those to which the whole membrane would reciprocate, it divides itself into distinct segments of vibration, which are separated by lines of rest; and every one of these reciprocates the sound,† at the same time rendering it more

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* "Philosophical Transactions," 1851.

† This is very easily proved by experiment on a membrane stretched over a resonant cavity; for if light sand be strewed upon it, and a strong musical tone be produced in

intense by multiplication (§ 631). These facts enable us to understand the influence of the *tensor tympani* muscle, in augmenting the tension of the membrane, and thus enabling it to vibrate in reciprocation to sounds having a great variety of fundamental notes. It appears to be antagonized by the *stapedius*, the contraction of which seems to diminish the tension of the membrana tympani, and to take-off pressure from the fluid of the labyrinth. These two muscles conjointly may be considered to regulate the transmission of sonorous undulations to the fluid of the internal sac, preventing it from being too violently affected by loud sounds, in the same manner that the iris regulates the admission of light to the eye (§ 608); and the analogy extends also to their nervous supply, the stapedius being excited to action by a branch of the Facial, whilst the tensor tympani receives its nerves from the Otic ganglion.* They are probably put into conjoint action when we are *listening* for faint sounds, so as to bring the tympanum into the state of tension best adapted to reciprocate them; whilst by a like preparation, the concussive effects of a loud sound that is *anticipated*, are more effectually moderated than when it strikes the ear without warning. It is probably owing to an imperfect action of these muscles, that some persons are deaf to grave sounds, whilst they readily hear the more acute.

635. The uses of the *Tympanic Cavity* are very obvious. One of its purposes is to render the vibrations of the membrane quite free; and the other, to isolate the chain of bones, in such a manner as to prevent their vibrations from being weakened by diffusion through the surrounding solid parts. As to the objects of the *Eustachian Tube*, opinions have been much divided. Many of these opinions, however,—such as the one most commonly entertained, that it serves the same purpose as the hole in an ordinary drum, removing an impediment to the free vibration of the membrane that would be offered by the complete inclosure of the air within,—are at once negatived by the fact, which seems to have been demonstrated by Mr. Toynbee, that the guttural orifice of the tube is usually *closed*, being only opened during the act of swallowing.† The principal object of the Eustachian tube (which is always found where there is a tympanic cavity) seems to be the maintenance of equilibrium between the air within the tympanum and the external air; so as to prevent inordinate tension of the membrana tympani, which would b produced by too great or too little pressure on either side, and the effec of which would be imperfection of hearing. It also has the office o conveying-away mucus secreted in the cavity of the tympanum, by means of the vibratile cilia which clothe its lining membrane; and the deafness consequent on occlusion of this tube, is in part explicabl by the accumulation which then takes-place in the cavity. From what has been stated, it is evident that sonorous undulations in th air will be propagated to the fluid contained in the labyrinth,–

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its vicinity, the membrane will immediately be set in vibration, not as a whole (unle its fundamental note be in unison with that sounded), but in different segments, which every one reciprocates the sound; from the vibrating parts, the sand will b violently thrown-off; but it will settle on the intermediate lines of rest, which a known as the *nodal* lines, forming a variety of curious figures.

* See Mr. C. Brooke in "Lancet," 1843, p. 380; and Mr. Toynbee in "Brit. a For. Med.-Chir. Rev.," vol. xi. p. 235.

† Loc. cit., and "Proceedings of the Royal Society," 1852.

through the tympanum, the chain of bones,* and the membrane of the *fenestra ovalis* to which the stapes is attached,—without any loss, but rather an increase of intensity. Why water should be chosen as the medium through which the impression is to be made upon the nerve, it is impossible for us to say with anything like certainty, in our present state of ignorance as to the physical character of that impression. But the problem being to communicate to water the sonorous undulations of air, the experimental results already detailed satisfactorily prove that—whilst this may be accomplished, in a degree sufficient for the wants of the inferior animals, by the simple interposition of a tense membrane between the air and the fluid,—the tympanic apparatus of the higher classes is most admirably adapted for this purpose. The fenestra ovalis is not, however, the only channel of communication between the tympanum and the labyrinth; for there is in most animals a second aperture, the *fenestra rotunda*, leading into the cochlea, and simply covered with a membrane. It is generally supposed that, the labyrinth being filled with a nearly incompressible fluid, this second aperture is necessary to allow the free vibration of that fluid; the membrane of the fenestra rotunda being made to bulge-out, as that of the fenestra ovalis is pushed-in. It may be easily shown by experiment, however, as well as by reference to comparative anatomy, that no such contrivance is necessary; for sonorous undulations may be excited in a non-elastic fluid, completely inclosed within solid walls at every part, except where these are replaced by the membrane through which the vibrations are propagated; and this is precisely the condition, not only of Invertebrated animals, but even ot Frogs; in which last a tympanic apparatus exists, without a second orifice into the labyrinth. Moreover it is certain, that the vibrations of the air in the cavity of the tympanum must of themselves act upon the membrane of the fenestra rotunda; and this is perhaps the most direct manner in which the fluid in the cochlea will be affected, although it will ultimately be thrown into much more powerful action, by the transmission of vibrations from the vestibule. For it has been satisfactorily determined by experiment (XII.), that vibrations are transmitted with very much greater intensity to water, when a tense membrane, and a chain of insulated solid bodies capable of free movement, are successively the conducting media, than when the media of communication between the vibrating air and the water are the same tense membrane, air, and a second membrane:—or, to apply this fact to the organ of hearing, the same vibrations of the air act upon the fluid of the labyrinth with much greater intensity, through the medium of the chain of auditory bones and the fenestra ovalis, than through the medium of the air of the tympanum and the membrane closing the fenestra rotunda.—The fenestra rotunda is not to be considered as having any peculiar relation with the cochlea; since, in the Turtle tribe, the former exists without the latter.

636. It is obviously in the *Labyrinth* as a whole, that the sonorous vibrations are brought to bear upon the Auditory nerve spread-out to receive them. In regard to the special functions of particular parts of the labyrinth, however, no certainty can be said to exist. The membrane

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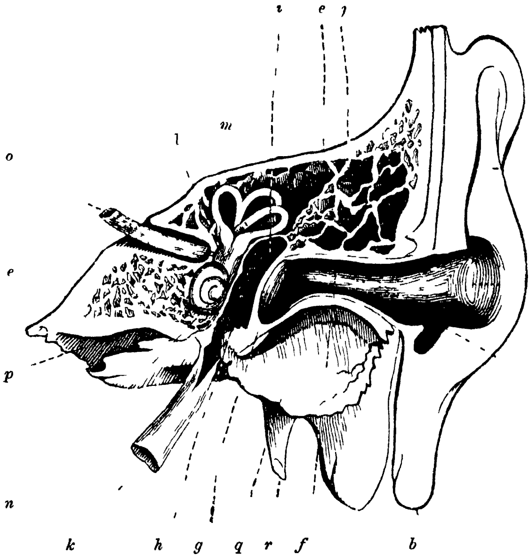
* For papers showing that sounds are chiefly conducted through the bones of the tympanum, see J. Jago, in "Proceedings of Royal Society," 1857–59, vol. ix. p. 134; and J. Toynbee, in idem, 1859–60, vol. x. p. 32.

which lines its cavities not only contains a liquid (the *endo-lymph*), but is also separated from the osseous wall by another collection of liquid, the *peri-lymph;* so that it is suspended, as it were, in a liquid which bathes both its surfaces. In the cavity of the Vestibule, which is subdivided by a membranous partition into two, are found small masses of concretionary particles, collectively named *otoconia*, or ear-powder; these are obviously the rudiments of the *otoliths*, or ear-stones, whose presence, in animals with a less perfect auditory apparatus, seems needful to intensify the undulations.—It is commonly supposed that the *Semicircular Canals* have for their peculiar function, to receive the impressions by which we distinguish the *direction* of sounds; and it is certainly a powerful argument in support of this view, that, in almost every instance in which these parts exist at all, they hold the same relative positions as in Man, their three planes being nearly at right angles to one another. The idea, however, must be regarded as a mere speculation, the value of which cannot be decided without an increased knowledge of the laws according to which sonorous vibrations are transmitted; but it receives a certain degree of confirmation from the curious movements witnessed by M. Flourens after section of one or other of these canals (§ 514).—Regarding the special function of the *Cochlea*, there is precisely the same uncertainty. It has been surmised by M. Dugès, that by the Cochlea we are especially

FIG. 140.



Vertical Section of the *Human Ear*, the internal portions on an enlarged scale —*a, b, c*, external ear; *d*, entrance to auditory canal, *f*, *e, e*, petrous portion of temporal bone, *g*, membrana tympani, *h*, cavity of the tympanum, the chain of bones being removed, *i*, openings from this cavity into the cells, *j*, excavated in the bone; on the side opposite the membrana tympani are seen the fenestra ovalis and rotunda, *k*, Eustachian tube, *l*, vestibule, *m*, semicircular canals, *n*, cochlea, *o*, auditory nerve, *p*, canal for carotid artery, *q*, part of glenoid fossa, *r*, styloid process.

enabled to estimate the *pitch* of sounds, particularly of the voice; and he adduces, in support of this idea, the fact, that the development of the cochlea follows a very similar proportion with the compass of the voice. This is much the greatest in the Mammalia; less in Birds; and in Reptiles which have little true vocal power, the cochlea is reduced to its lowest form, disappearing entirely in the Amphibia. That there should be an acoustic relation between the voice and ear of each species of animal, cannot be regarded as improbable; and the speculation of M. Dugès derives confirmation from the researches of Helmholtz, who appears to consider that the function of the cochlea stands in intimate relation with our power of discriminating differences in the *quality* of sounds. This will naturally follow from his demonstration that the *timbre* depends upon the harmonic combinations; if it be the function of the cochlea to discriminate *pitch*. According to his observations, the individual branches of the auditory nerve are only capable of distinguishing simple, pendulum-like vibrations; but, as already stated (§ 629), all ordinary sounds are compound in their nature, the fundamental note being accompanied by harmonics; these throw corresponding fibres into vibration, and produce an impression which may be likened to a colour. The analogy which exists between the power of distinguishing *colours* and that of discriminating musical *tones* has long been recognized; and whilst we find that some persons are endowed with the latter, which is commonly known as a 'musical ear,' in a degree that renders it a source of great discomfort to them (since every discordant sound is a positive torment), others are altogether destitute of it,—the deficiency being very analogous to the 'colour-blindness' formerly described (§ 621). It is not a little curious, that the two defects are occasionally co-existent in the same individuals.*

637. We have now to consider the functions of the accessory parts,—the *External Ear*, and the *Meatus*. The Cartilage of the external ear may propagate sonorous vibrations in two ways; by reflection, and by conduction. In reflection, the concha is the most important part, since it directs the reflected undulations towards the tragus, whence they are thrown into the auditory passage. The other inequalities of the external ear cannot promote hearing by reflection; and the purpose of the extension of its cartilage is evidently to receive the sonorous vibrations from the air, and to conduct them to its source of attachment. In this point of view the inequalities become of importance; for those elevations and depressions upon which the undulations fall perpendicularly, will be affected by them in the most intense degree; and in consequence of the varied form and position of these inequalities, sonorous undulations, in whatever direction they may come, must fall advantageously upon some of them.—The functions of the Meatus appear to be threefold. The sonorous undulations entering from the atmosphere are propagated directly, without dispersion, to the membrana tympani: the sonorous undulations received on the external ear are conveyed along the walls of the meatus to the membrana tympani: whilst the air which it contains, like all insulated masses of air, increases the intensity of sounds by resonance. That, in ordinary hearing, the direct transmission of atmospheric vibra-

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* See a collection of such cases by Dr. Pliny Earle, in "Amer. Journ. of Med. Sci.," vol. xxxv.

tions to the membrana tympani is the principal means of exciting the reciprocal vibrations of the latter, is sufficiently evident; the undulations which directly enter the passage, will pass straight on to the membrane; while those that enter obliquely will be reflected from side to side, and at last will fall obliquely on the membrane, thus perhaps contributing to the notion of direction. The power of the lining of the meatus to conduct sound from the external ear, is made evident by the fact, that, when both ears are closely stopped, the sound of a pipe having its lower extremity covered by a membrane, is heard more distinctly when it is applied to the cartilage of the external ear itself, than when it is placed in contact with the surface of the head. The resonant action of the air in the tube is easily demonstrated, by lengthening the passage by the introduction of another tube; the intensity of external sounds, and also that of the individual's own voice, as heard by himself, is then much increased.

638. Many facts prove, however, that the fluid of the Labyrinth may be thrown into vibration in other ways than by the Tympanic apparatus Thus in Osseous Fishes, it is only by the vibrations transmitted through the bones of the head, that hearing can take place. There are many persons, again, who can distinctly hear sounds which are thus transmitted to them; although, through some imperfection of the tympanic apparatus, they are almost insensible to those which they receive in the ordinary way. It is evident, where this is the case, that the nerve mus be in a state fully capable of functional activity; and on the other hand where sounds cannot thus be perceived, there will be good reason to believe that the nerve is diseased.

639. The power of distinguishing the *direction* of sounds appears to be in Man at least, for the most part acquired by habit; for it is some time before the infant seems to know anything of the direction of noises which attract his attention. Our judgment as to this point is probably assisted in most cases, by a difference in the intensity of the sensations received through the two ears respectively; but since we have a certain power o appreciating direction when one ear alone is used, this power must depend upon an exercise of perceptive discrimination (which is probably acquired, rather than intuitive,) in regard to the impressions which we receive through its means; and it has been already mentioned that the Semicircular canals (§ 636) appear to furnish the instrumentality by which our minds are enabled to take cognizance of such differences.—The idea of the *distance* of the sonorous body is another acquired perception, depending principally upon the loudness or faintness of the sound when we have no other indications to guide us. In this respect there is a great similarity between the perception of the distance of an object through the Eye by its size, and through the Ear by the intensity of its sound. When we are acquainted with the usual intensity of its sound we can judge of its distance; and *vice versâ*, when we know its distance we can at once form an idea of its real strength of tone from that with which our ears are impressed. In this manner, the mind may be affected with corresponding deceptions through both senses: for as, in the Phantasmagoria, the figure being gradually diminished whilst its distance remains the same, it appears to the spectators to recede (the illusion being more complete if its brightness be at the same time diminished); so th effect of a distant full military band gradually approaching, may be alik

given by a corresponding *crescendo* of concealed instruments. It is upon the complete imitation of the conditions which govern our ideas of the intensity and direction, as well as of the character, of sounds, that the deceptions of the Ventriloquist are founded. A very curious instance of the degree in which our auditory interpretation is affected by other sense-perceptions, is afforded by the 'Ghost' exhibition which has recently been so popular; for it is scarcely possible to avoid referring to the place where they *seem* to be made, sounds which are really produced elsewhere.

640. The Auditory sense, like the visual, may vary considerably among different individuals, both as regards its general acuteness, and as respects its discriminative power for particular classes of impressions. Much depends upon the *habit of attention* to its indications; and thus it comes to pass, that the power of hearing very faint sounds and of recognizing their source, becomes augmented to a wonderful degree in those individuals who are obliged to trust to the knowledge thus acquired for the direction of their own actions; whilst, in like manner, the power of distinguishing slight differences in the pitch of sounds, may be so cultivated (where it is not congenitally deficient) as to attain an intensity that seems very extraordinary to those who have not accustomed themselves to listen for them. The general cultivation of this sense is perhaps most remarkable in blind persons, who have enabled themselves, by reliance upon it, to walk-about freely, even in the crowded thoroughfares of the Metropolis; and who are not only able to judge of the habits of individuals whom they meet, by the sound of their footsteps (at once recognizing, for instance, the footstep of a policeman on duty), but can even tell when they are passing a stationary object (such as a lamp-post), provided it be as high as the ear or nearly so, by the reverberation of the sound of their own footsteps, and can discriminate between a lamp-post and a man standing-still in the position of one, by the same means.* The effect of habitual attention in increasing the discriminative power for impressions of one particular kind, is perhaps best seen in the ability which is possessed by certain Conductors of orchestral performances, to detect the slightest departure from time or tune in the sound of any one of (perhaps) a hundred instruments that are simultaneously sounding, and to fix without hesitation upon the faulty instrumentalist. Seebeck, indeed, affirms that accomplished musicians can detect a difference in pitch between two sounds which only differ by 1-1200th in the number of their vibrations.† According to the researches of MM. Renz and Wolff,‡ our faculty of estimating differences in the intensity of sounds is much less perfect. When the intensities of two sounds are to one another as 7 to 10, the difference can be distinguished, but not when they are in the relation of 9 to 10. The advantage resulting from the simultaneous employment of the two ears in distinguishing minute differences in the intensity and pitch of sounds, is well shown in the experiment suggested by M. Weber, of holding two watches in the hand before one ear, when it will be found that the succes-

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[*] See the ccount of a blind boot-lace-seller given by Mr. H. Mayhew, in his "London Labour and the London Poor," vol. i. p. 402.

[†] See Ludwi ysiologie," vol. i. p. 380; and Béclard, "Physiologie," 1862, p. 1858.

[‡] " ys. Heilk.," 1856.

sive sounds can be distinctly heard, though they cannot be distinguished one from the other, whilst if one be held in front of each ear the two sounds can be clearly discriminated.

641. Facts of much interest have been ascertained, some of which have been already alluded-to (§ 452), in regard to an occasional difference in the rapidity of the perception of sensory impressions, received through the Eye and through the Ear respectively. These facts are the result of comparisons made amongst different Astronomical observers, who may be watching the same visual phenomenon, and 'timing' their observations by the same clock; for it has been remarked, that some persons see the same occurrence, a third or even a half of a second *earlier* than others. There is no reason to suppose from this, however, that there is any difference in the rate of transmission of the sensory impressions in the two nerves. The fact seems rather to be, that the Sensorium does not readily perceive two impressions of different kinds with equal distinctness; and that, when several such impressions are made on the senses at the same time, the mind takes cognizance of one only, or perceives them in succession. When, therefore, both sight and hearing are directed simultaneously to two objects, the communication of the impression through one sense will necessarily precede that made by the other. The interval between the two sensations is greater in some persons than in others; for some can receive and be conscious of many impressions seemingly at the same moment; whilst in others a perceptible space mus elapse. The 'personal equation' of each observer in an Observatory has, therefore, to be determined and allowed-for.*

642. Amongst other important offices of the sense of Hearing, is that of supplying the sensations by which the Voice is regulated. It is wel known that those who are born entirely deaf, are also dumb; that is they do not spontaneously or imitatively form articulate sounds, though not the least defect may exist in their organs of voice. Hence it appears that the vocal muscles are usually guided in their action by the sensations received through the Ears, in the same manner as other muscles are guided by the sensations received through themselves; but when the former are deficient, the action of the vocal muscles may be guided by the latter (§ 525).

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* In all the best Observatories, an arrangement is now made for recording observations which supersedes the necessity of timing them by simultaneous attention to the clock. The observer who is watching the transit of a star (for example) across the meridian, simply presses a button at the moment when he witnesses its contact with the cross-wire. This pressure breaks an electric circuit, which is so connected with a chronometer as to stop it instantaneously, and thus automatically to record the precise time of the phenomenon. Since this plan has been adopted, it has been found that the "personal equation" nearly or altogether disappears; thus confirming the view given above as to its dependence on the distraction of the attention between the two objects o perception.

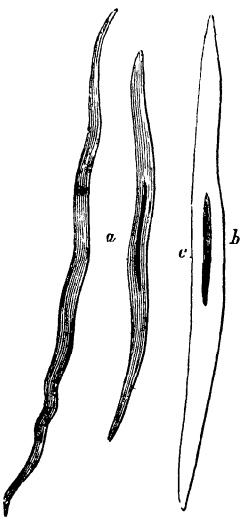
CHAPTER XIII.

ON THE STRUCTURE AND FUNCTIONS OF MUSCULAR TISSUE.

1. *Structure of Muscular Tissue.*

643. MUSCULAR tissue, if under this term be included the instrument by which all the sensible movements of the body are accomplished, exists under three forms. The first, by which the movements of ciliated cells are effected, has hitherto proved too subtle for microscopical analysis, and can only be described as a clear homogeneous and apparently structureless material, capable, however, of executing very rapid and energetic vibratory movements, the object of which appears to be limited to the establishment of currents, usually directed towards the exterior of the body, in the fluids covering the surface of various membranes; as in the case of the respiratory and female generative tracts. These movements do not appear to be in any way under the control of the nervous system, since they persist long after somatic death; nor are they materially affected by chemical or medicinal agents, unless these are sufficiently powerful in their operation to produce structural or organic changes. The undulating movements which have been observed in the spermatozoa appear to belong to the same category as those exhibited by ciliated cells.

FIG. 141.



Fusiform cells of *Smooth Muscular Fibre*, from the renal vein of Man:—*a*, two cells in their natural state, one of them showing the staff-shaped nucleus; *b*, a cell treated with acetic acid, with its nucleus *c* brought strongly into view.

644. The second form of muscular tissue consists of flattened bands, which are stated by Kölliker to be composed of long, fusiform cells (Fig. 141) with staff-shaped, elongated nuclei; the length of the cells varying from 1-50th to 1-1125th of an inch, and their breadth from 1-1125th to 1-5625th of an inch. Prof. Ellis* has recently, however, thrown some doubt upon the cellular character of unstriated muscular tissue; and has described it as composed of long, slender, rounded cords of uniform width, except at the ends, where they are fixed by tendinous tissue; the fibres being interwoven into a kind of meshwork, and varying greatly in size in the same bundle. This form of muscular tissue is found in a pure state, unmixed with other tissue, in the nipple, corium, ciliary muscle, intestinal canal, bladder, prostate, vagina, and in the smaller arteries, veins, and lymphatics; and mingled with much areolar, fibrous, and elastic tissue in the trabeculæ of the spleen

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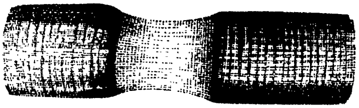
* See "Proceedings of the Royal Society," vol. viii. p. 212, and vol. ix. p. 573.

and corpora cavernosa, the dartos, the circular fibres of the larger arteries and veins, the urethra, Fallopian tubes and uterus, and also in the trachea and bronchi.

645. The third variety of Muscular tissue presents transverse striæ under the microscope, and occurs in all those muscles that are usually termed "voluntary," though its presence in the heart, rectum, and pharynx shows that it is not limited to these alone. On examining the structure of a striated muscle it is found to be easily separable into coarser or finer *fasciculi* connected by means of areolar tissue, which on more minute dissection can be shown to consist of transversely striated polygonal *fibres*, having, in Man, an average diameter of 1-400th of an inch. The fibres frequently terminate by free pointed extremities in the muscle; at other times they become continuous, either abruptly or by imperceptible gradation with tendinous or strong connective-tissue fibres.* In rare instances they anastomose, as in the heart (Skey). During life the fibres appear to be semitransparent and of soft consistence.† After death each fibre can be split either longitudinally into *fibrillæ*, the number of which has been estimated at six or seven hundred, or transversely into a series of disks; the average diameter of the fibrillæ is 1-9400th of an inch in man, and they are bound together by a transparent sheath, the sarcolemma (Fig. 142). On the surface of the sarcolemma and sometimes in the interior of the fibre are nuclei containing one or more nucleoli, and readily brought into view by the action of acetic acid. According to some observers these are to be regarded as the remains of the original cells from which the muscular fibres were developed; others have regarded them as centres from whence new muscular fibres may originate; others as the corpuscles of the connective tissue distributed through the muscle, and therefore centres of nutrition analogous to the lacunæ of bone; and still more recently it has been maintained that they are in connection with the ultimate terminations of nerves. The exact structure of the fibrillæ is still doubtful. Under high powers of the microscope they appear to consist of alternate rectangular light and dark particles, constituting the "sarcous elements" of Mr. Bowman. The dark particles are thicker than the light ones, and in consequence of their being less easily acted-on by dilute hydrochloric acid and gastric juice, can be obtained in a detached or separate state after short exposure to the action of either of these fluids. Brücke has described the dark particles as refracting light doubly, whilst the clear intervening substance is only singly refractile.‡ Dr.

FIG. 142.



Muscular Fibre broken across, showing the untorn *Sarcolemma* connecting the fragments.

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* As in the tongue, Hyde Salter in "Cyclop. Anat. and Phys.," vol. iv. p. 1132. Hoyer, however, maintains that in such instances the transparent fibres in which the muscular fibres apparently terminate are in reality contractile. See "Reichert's Archiv," 1859, p. 481.

† Kühne observed a Nematoid worm move with apparent freedom in the interior of a fibre; his observation is quoted in Hermann's "Grundriss der Phys.," 1863, p. 180.

‡ Brücke further regards the dark particles as uniaxial positive crystals, having their axis parallel to the direction of the fibres, and as being composed of minute solid doubly-refracting particles, which he terms *disdiaclasts*.

Martyn,* in examining a fortunate specimen of muscular tissue under a very high power (1200 linear), observed large and small sarcous elements to occur alternately, as had previously been described by Busk and Huxley;† the smaller ones evidently corresponding to the faint transverse line traversing the clear space long ago perceived and described by Dr. Sharpey and the Author, from careful observation of Mr. Lealand's preparations. The muscles receive a free supply of blood, the capillary vessels being arranged in oblong meshes; but their lymphatics are either altogether absent or exceedingly few in number.‡ The mode of termination of the nerves in muscle has recently been the subject of much investigation.§ According to Kühne the motor nerves divide and subdivide till the fibres run alone or only in bundles of two or three on the outside of the muscular fibres. After a short course, however, they penetrate the sarcolemma, losing at the same time their sheath and the white substance of Schwann; whilst the axis cylinder, dipping in and branching amongst the fibrillæ, terminates in a chain of nuclear-like vesicles or pale ganglionic cells, from which extremely delicate pencils or brushes of fibres may be observed to issue. Engelmann describes the axis cylinder after penetrating the sarcolemma, as terminating in a kind of disk or plate, which melts by imperceptible gradations into the tissue of the muscle itself. Kölliker and Beale, on the other hand, deny the penetration of the sarcolemma by the ultimate branches of the nerves, but describe them as forming a plexus, composed of pale fibres of extraordinary tenuity (1-100,000th of an inch), intermingled with many nuclei lying on and ramifying *over* the fibres.

646. The chemical composition of muscular fibre seems to be very uniform, from whatever source it is obtained. It is impossible, however, to determine it with precision, on account of the difficulty of completely isolating the substance of the fibres from the areolar tissue, vessels, and nerves that are blended with them. According to the analysis of v. Bibra, ox-flesh freed from fat contains in 1000 parts 776 of water and 224 of solid substances; of the latter 20 parts were found to consist of soluble albumen and colouring matter, 20 parts of gelatine, 30 parts were extracted by alcohol, and the remaining 154 parts were composed of vessels and syntonine, the latter forming the basis of muscular tissue, and being allied to albumen in its physical and chemical properties. Amongst the extractive matters which have been discovered by various chemists, may be enumerated creatine and creatinine,—uric, lactic, inosinic, formic, acetic, butyric, and other fatty acids,—some saccharine compounds, as inosite and amyloid substance,—red pigment, mineral salts, especially those of potassium, and phosphates, with a certain proportion of carbonic acid and oxygen gases.—Some very interesting researches have been made by Helmholtz‖ on the chemical changes induced in the tissue by muscular action. Powerful contractions were induced by electricity in the amputated leg of a frog, and were kept up as long as the irritability was

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* "Beale's Archiv," 1862, p. 227.

† Note to Kölliker's "Man. of Hum. Histology," Syd. Soc. Trans., vol. i. p. 239.

‡ Teichmann, "Das Saugader System," 1861, p. 100.

§ See Kühne, "Ueber die Peripheric Endorgane der Motor Nerven," 1862; Engelmann, T. W., "Untersuch. üb. d. Zusammenhang v. Nerv- u. Muskel-faser," Leipzig, 1863; Kölliker, Croonian Lecture, 1862; Beale, "Archives of Medicine," vol. iii. 1862, p. 246; and "Philosophical Transactions," 1863.

‖ "Müller's Archiv," 1845.

retained; the flesh of the two limbs was then analyzed, and it was found that in every instance the water extractive was diminished in the electrised muscle to the extent of from 20 to 24 per cent, whilst the alcoholic extract was increased to about the same amount, showing an increase in the proportion of those products which we know to result from the retrograde metamorphosis of muscular substance consequent upon its functional activity.—Ranke,* pursuing the same line of research, has shown that the diminution in the contractile power of an exhausted (tetanized) muscle is essentially produced by the presence of lactic acid, associated no doubt with other products of disintegration in the substance of the tissue; for whilst the injection of a stream of water containing 0·5 per cent of common salt into the vessels rapidly restored the contractile power to the exhausted muscle, the introduction by the same means of the juice of muscle, and especially of lactic acid in solution in water, immediately depressed or even altogether abolished the contractile property. Hence he draws the conclusion, that if due provision for the supply of nutritive and for the removal of disintegrated material be present, the tissue itself, however strenuously exerted, would still be capable of developing force; and that the failure of this power in ordinary circumstances is attributable not to a deficiency of nutritive materials, but to inadequacy of the means requisite for the carrying-off of the waste products generated by its action.

647. *Development of Muscular Tissue.*—In Man, according to Mr. Lockhart Clarke,† Muscular Fibre can first be distinguished about the 4th or 5th week of utero-gestation. In a fœtus of three-fourths of an inch in length, it forms a gelatinous mass consisting of fibres and nuclei imbedded in a semifluid granular blastema. In the formation of the fibres, granular processes of condensed blastema extend from the sides or from around the nuclei, which are subsequently bounded by an investing substance in the form of a band or fibre, sometimes plain, but sometimes longitudinally fibrillated. In these bands the transverse striation first makes its appearance, and only subsequently extends through the central band or axis. The muscular fibres vary in size at different parts, and they may sometimes be seen to increase in diameter by the adhesion of fresh nuclei and fresh processes of blastema. A very similar account has been given by Mr. Savory for the Mammalia generally,‡ except that in his observations the nuclei, at first irregularly distributed, were found to arrange themselves with great regularity in single rows, almost in contact with one another, the fibres being formed by the development of two nearly transparent bands enclosing and bounding the rows of nuclei; subsequently the nuclei began to separate from one another, and ultimately broke-up into granules and disappeared. The striation began within the border and gradually extended to the centre. Increase in the size of the fibres was effected by the addition of fresh blastema to the outer side of existing fibres. From both descriptions it is obvious that the essential features of the process occur not in the nuclei, nor in cells, as was originally maintained by Schwann, but in a material which may be regarded as intercellular substance; and Mr. Lockhart

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* Reichert and Du Bois-Reymond's "Archiv," 1863, p. 422.

† "Proceedings of the Royal Society," vol. xi. No. 48.

‡ See Part ii. of the "Phil. Trans." for 1855.

Clarke regards even involuntary muscular fibres as by no means the *product* of a nucleated cell, but rather as a kind of cell-formation, presenting at first a nucleus encrusted with blastema, around which an investing sarcous substance representing the cell-wall is subsequently developed.

648. The ordinary rate of *Nutrition* of the muscular tissue depends upon its functional activity. Every exertion of its vital contractility involves a waste or disintegration of a proportional amount of its substance; and the products of the chemical changes which the tissue ordinarily undergoes when at rest, can easily be shown to be greatly increased in quantity. Hence upon the principle of 'the conservation of force,' it would appear that the power which previously manifested itself in the performance of the acts of growth and development, being now no longer directed to these objects, is expended in the form of mechanical power; the organic compounds coincidently assuming much simpler forms, as is evidenced by the experiments of Helmholtz and of Dr. Ed. Smith, already referred-to (§§ 288 VII. 646). The increase of the demand for food occasioned by muscular activity is an indication that the nutritive operations are excited by it; and the purpose of these can scarcely be anything else than the reparation of the loss which the muscle has sustained. Moreover, the frequently renewed exercise of muscle, by producing a determination of blood towards them, occasions an increase in their nutrition; so that a large amount of new tissue is developed, and the muscles augment in size and vigour. This is true not only of the whole muscular system when equally exercised, but also of any particular set of muscles which is more used than another. Of the former we have an example in those who practise a system of gymnastics adapted to call the various muscles alike into play; and of the latter in the limbs of individuals who follow any calling that habitually requires the exertion of either pair, to the partial exclusion of the other, as the arms of the smith, or the legs of the opera-dancer. But this increased nutrition cannot take place unless an adequate supply of food be afforded; and if the amount of nutritive material be insufficient, the result will be a progressive diminution in the size and power of the muscles, which will manifest itself the more rapidly as the amount of exertion, and consequently the degree of *waste*, is greater. Nor can it be effected if the exercise be incessant, for it is during the intervals of repose that the reparation of the muscular tissue occurs; and the Muscular system, like the Nervous, may be worn-out by incessant use. The more violent the action, the longer will be the period of subsequent repose required for the reparation of the tissue; and the longest time will of course be requisite when (as sometimes occurs) the contractility of the muscle is so completely exhausted by excessive stimulation that no new manifestation of it can be excited. It does not appear improbable that there is a provision in *some* Muscles, as the Heart and Respiratory muscles, by which their nutrition is carried-on with unusual activity during the short period of repose which intervenes between two successive contractions.

649. But, on the other hand, the muscular tissue, like all the softer and more decomposable portions of the organized fabric, has a limited term of existence; and hence, even if its contractility be not called into exercise, it undergoes a gradual disintegration, so soon as all the nutritive changes of its fibres are completed. This change seems to be a necessary con-

sequence of the high temperature of the bodies of warm-blooded animals; for it does not occur with nearly the same rapidity in cold-blooded animals, nor in the hybernating condition of certain warm-blooded Mammalia; indeed, when the temperature of the body is reduced to within a few degrees of the freezing point, no chemical change seems possible in muscle—its spontaneous decay and its vital activity being alike checked. Now, when a muscle or set of muscles in a warm-blooded animal is reduced to a state of prolonged inactivity, from whatever cause, its supply of blood is diminished, and its spontaneous decay is not compensated by an equally active renewal; so that in time, the characters of the structure are changed, and its distinguishing properties are no longer presented. Thus it was found by Dr. John Reid* that in a rabbit, a portion of whose sciatic nerve had been removed on one side, the muscles of that leg were but very feebly excited to contraction by galvanism after the lapse of seven weeks. The change in their nutrition was evident to the eye, and was made equally apparent by the balance. The muscles of the paralyzed limb were much paler, smaller, and softer than the corresponding muscles of the opposite leg, and they scarcely weighed more than half—being only 170 grains, whilst the others were 327 grains. It was found also that a perceptible difference existed in the size of the bones of the leg, even after so short an interval had elapsed; the tibia and fibula of the paralyzed limb weighing only 81 grains, whilst those of the sound limb weighed 89 grains. On examining the muscular fibres with the microscope, it was found that those of the paralyzed leg were considerably smaller than those of the sound limb, presenting a somewhat shrivelled appearance, and that the longitudinal and transverse striæ were much less distinct. So in persons whose lower extremities have been long disused, the muscles first become pale and flabby; their bulk gradually diminishes; their contractile force progressively decreases, and at last departs almost entirely; and their proper structure is replaced by a deposit of fat, in which few or no striated muscular fibres can be detected. But muscles that have for some time remained in this condition may be gradually brought back to their original state by exercise, provided that the feeblest contractility remains; for every action which they can be made to perform determines an augmented flow of blood through the tissue, and gives rise to an improvement in its nutrition, which in its turn increases its contractility and renders it capable of more vigorous action. This principle is of great importance in the treatment of the various forms of paralysis (especially the hysterical), in which the muscles are thrown out of use by the suspension of the functional power of the nerves; for when the latter have recovered their capacity, the muscles refuse obedience to their stimulation, and can only be brought to act by persevering and judiciously contrived exercise.—But notwithstanding the energy of nutrition in muscular tissue, the rapid interstitial change which takes place in it when actively exercised, and the complete restoration of its normal constitution after degeneration from disuse, it is doubtful if any true *regeneration* ever takes place in it, when there has been actual loss of substance. Wounds of muscles are united by connective tissue, which gradually becomes condensed, but the fibres of which never acquire any degree of contractility.

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* "Edinb. Monthly Journ. of Med. Science," May, 1841; and "Physiological, Anatomical, and Pathological Researches," p. 10.

650. Muscles exist in two states, the elongated and the contracted; the former is usually termed their state of *rest*, in which they immediately respond to the application of stimuli, whether direct or indirect, by passing into the active state of contraction. Dr. Radcliffe[*] has, however, adduced many arguments to show that the ordinarily received statement above given should be reversed, and that the state of elongation should be regarded as the really active condition of muscular fibre, in which all its vital properties and peculiarities are most strongly marked; whilst the state of contraction is due to its being left to the influence of the attractive forces inherent in its molecules, the most energetic operation of which is seen in the rigor mortis. The physical, chemical, and electrical properties of muscles differ considerably in the two states of elongation and contraction, and they may therefore be compared together.—In contraction the muscles become softer, shorter, and thicker, and diminish slightly in volume.[†] Their elasticity and electrical relations are modified, and heat and sound are produced. The amount of shortening which a muscle will undergo, bears a direct relation to the resistance; and by opposing a sufficient resistance, the contractile power of the muscle may be powerfully exerted without any contraction taking place. Under ordinary circumstances the striated muscles do not contract much more than one-third of their length, being restrained by the mechanical arrangements of the bones and joints, and by the antagonistic muscles. But if a long muscle of a frog be removed from the body and powerfully stimulated, it will contract to one-fifth of its original length. The unstriped fibres will contract under favourable circumstances to about one-third of their length.

651. The rapidity with which the mandates of the Will are communicated to and executed by the Muscles is immeasurable; but Helmholtz has shown that if an electric spark, whose duration does not exceed one six- or seven-hundredth of a second, be allowed to strike a portion of fresh muscle, a measurable period, amounting to 1 or 2-100ths of a second, intervenes before the commencement of contraction. This he terms the period of latent contraction or excitation. The contraction which then takes place is not sudden and complete, but is divisible into two stages, in the first of which the muscle rapidly, and in the second more slowly, contracts till it attains its maximum; it then begins to elongate, at first slowly, and then more rapidly. The period of time which elapses from the instant that the stimulus is applied until the contraction is complete, increases generally with the amount of shortening, with the heaviness of the weight, and with the exhaustion of the muscle. In the Frog the entire time occupied in the contraction and subsequent elongation of a muscle was about one-third of a second, of which

	Of a second.
The period of latent excitation amounted to	0·02
,, contraction ,, ...	0·180
,, elongation ,, ...	0·105
	·287[‡]

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[*] See his "Epileptic and other Convulsive Diseases of the Nervous System," 3rd edit. 1860, and his "Lectures on Epilepsy, Pain, and Paralysis," 1864.

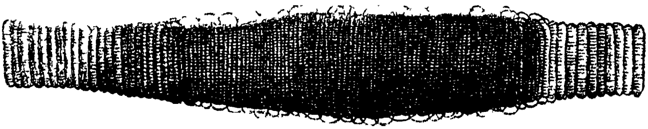
[†] Harless, "Abhand. Münch. Akad.," 1862, p. 357.

[‡] See Helmholtz in "Müller's Archiv," 1850, 1852; and Volkmann in "Leipzig Berichte Math. Phys. Class.," 1851.

From the results of various experiments, Helmholtz satisfied himself that muscles require a longer time to develope their greatest force, as when heavy weights were raised, than when slight efforts only were made.

652. From the inquiries of Mr. Bowman, it appears that the act of contraction usually commences at the extremities of the fibre; but it frequently occurs also at one or more intermediate points. The first appearance is a spot more opaque than the rest, caused by the approximation of a few of the dark points of some of the fibrillæ; this spot usually extends in a short time through the whole diameter of the fibre; and the shading caused by the approximation of the transverse striæ increases in intensity. The striæ are found to be two, three, or four times as numerous in the contracted as in the uncontracted part, and are also proportionally narrower and more delicate. The line of demarcation between the contracted and uncontracted portions is well defined; but as the process goes on, fresh striæ are absorbed as it were from the latter into the former. The contracted part augments in thickness, but not in a degree commensurate with its diminished length, so that its solid parts lie in smaller compass than before,—the fluid which previously intervened between them being pressed out in bullæ under the sarcolemma. The velocity with which the wave of contraction is propagated through muscle in Frogs has been ingeniously estimated by Aby* to be about 40 inches per second, or about 26 times slower than the propagation of a stimulus through the motor nerves.—The peculiar *sound* heard during the contraction of striated muscle may be perceived, as suggested by Dr. Wollaston† by placing the tip of the little finger in the ear, and contracting the muscles of the ball of the thumb, or by powerfully exerting the muscles which close the jaw. It resembles the distant rumbling of carriage wheels, or an exceedingly rapid and faint tremulous vibration, which, when well marked, has an almost metallic tone. From various experiments made upon himself and others, Professor Haughton estimates that the number of vibrations varies from 32 to 36 per second. The sound may be readily conceived to depend upon the friction of the elements of the muscle, one upon another, which must thus be perpetually taking place so long as it continues in a state of activity.—The careful experiments of Helmholtz with a thermo-electric apparatus of extreme delicacy, have shown that in the muscles of Frogs *a rise in temperature* takes place during contraction, amounting to somewhat less than 1-3rd of a degree Fahren-

FIG. 143.



Muscular Fibre of Dytiscus, showing the *contracted state* in the centre; the striæ approximated; the breadth of the fibre increased; and the myolemma raised in bullæ on its surface.

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* "Canstatt's Bericht," 1862, pp. 3 and 151.
† "Philosoph. Trans.," 1811.

heit. Solger* and Meyerstein and Thiry† have observed that at the commencement of contraction a muscle becomes sensibly cooler than before. This effect lasts several seconds, and may perhaps be attributed to a diminution of the specific heat of muscle in contraction; it is followed by a gradual increase in temperature, which, if the muscle be tetanized, continues for some time after contraction has ceased; and proceeds, in all probability, partly from the continuance of a more energetic process of oxidation, indicated by the increased production of carbonic acid, and partly from an increased flow of blood through the vessels of the muscle. According to Meyerstein and Thiry, the amount of heat generated is always in proportion to the amount of work done.

653. Muscles, whether in the contracted or elongated state, possess a certain amount of elasticity. By this term is meant that force by which the particles of any substance, after being approximated to or separated from one another, strive to regain their original position. The elasticity of muscular fibre is small, but remarkably perfect; for although it is extended considerably by a light weight, it recovers itself completely on the removal of the extending force.‡ That it is exceedingly small, even during life, is shown, as Mansvelt has observed,§ by the fact that in cases of paralysis of the third nerve the pupil is for some days brought quite into the middle of the space between the eyelids solely through the *elastic* contraction of the rectus internus; a proof that its antagonist, in a state of elongation, exercises no force worth speaking of. On appending a small weight to a vertically-suspended fresh muscle, it at first elongates suddenly and considerably (the primary extension), then much more slowly (the secondary extension). On removing the weight, the same phenomena appear in inverse order; a considerable primary, and a more gradual and smaller secondary retraction. With small weights the increase in length is proportional to the weight; with heavier weights a greater proportional weight is required to produce the same amount of extension, as is shown in the following experiment made by Weber‖ with the Hypoglossus of a Frog:—

Weight in Grammes successively applied to the Muscle.	Length of the Muscle in Millimetres.	Extension.	
		In Mm.	Per Cent.
0·3	24·9	—	—
1·3	30·0	5·1	20
2·3	32·3	2·3	7
3·3	33·4	1·1	3
4·3	34·2	0·8	2
5·3	34·6	0·4	1

Mansvelt, however, deduces as the principal result of his experiments, that living muscle is, at least within certain limits, extended in proportion to the increase of the weights, each fibre elongating about 1 per cent of its length for each 65th of a grain weight appended to it. According to Wundt, the weight which is required to extend a fresh muscle of 1 square millimetre (1-25th of an inch) sectional area, twice its length, is 2 oz. The muscles are constantly in a state of slight tension, as is shown by the separation of their extremities when cut; but it would obviously have seriously interfered with their action had a high degree of elasticity been conferred upon them, since antagonistic muscles would have had this, in addition to all other resistances, to overcome, before movement could be effected. Weber has shown that the elasticity of muscles diminishes during contraction. He applied a weight of 115 grains to an elongated muscle. On the addition of another weight of 15½ grains, the amount of extension which took place was about 1-144th of its length; but on repeating the same experiment with a contracted muscle, the extension was as much as 1-79th of its length, showing that the extensibility was greater in the latter case than in the former. The exhaustion of a muscle greatly increases its extensibility up to a certain point, after which it again diminishes. Thus, when a portion of muscle was weighted with 115 grains, its greatest extension occurred when it had been made to contract 43 times; when weighted with 193 grains after 23 contractions; and lastly, when weighted with 424 grains at the 8th contraction. It was even found that, by appropriate weighting, a muscle on being stimulated to contract might actually become longer instead of shorter.

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* "Studien des Physiolog. Instituts zu Breslau," 1863, p. 125.

† Henle and Pfeuffer's "Zeits. f. Rat. Med.," band xx. 1863, p. 45.

‡ Heidenhain, "Studien," Berlin, 1856; and Wundt, "Müller's Archiv," 1857.

§ See a Review of his work in the "Med.-Chir. Rev." for 1864, p. 443, vol. i.

‖ "Wagner's Handwörterbuch," band iii. p. 54.

654. *Electrical Relations of Muscle.*—As we have already seen in the Nerves, so in the Muscles it is easy to furnish evidence of electrical disturbance. The conditions of the 'Muscular current' have been made the subject of special investigation by M. du Bois-Reymond; and the following is an outline of the results at which he has arrived, for the due comprehension of which, however, it is requisite that the terms employed by him should be first defined.—The entire muscle being composed of a mass of fibres, having a generally-parallel direction, and attached at their extremities to tendinous structure (which has in itself but little or no electromotor power, but is a conductor of electricity), it follows that the tendon or tendinous portion of a muscle represents a surface formed by the *bases* of the muscular fibres considered as prisms, which may be designated its *natural transverse section.* On the other hand, the fleshy surface of the muscle, which is formed only by the *sides* of the fibres considered as prisms, may be regarded as the *natural longitudinal section* of the muscle. Again, if a muscle be divided in a direction more or less perpendicular to its fibres, an *artificial transverse section* will be made; whilst if the muscle be torn lengthways in the direction of its fibres, an *artificial longitudinal section* will be made; and these artificial sections show the same electric conditions with their corresponding natural sections. Now, experiments repeated in a great variety of modes demonstrate, that *every point in the natural or artificial longitudinal section of a muscle is positive in relation to every part of its transverse section, whether natural or artificial;* the most powerful influence on the galvanometer being produced, when a portion of the surface (or natural longitudinal section) of a muscle is laid upon one of the electrodes, and a portion of the surface formed by cutting the muscle across (or artificial transverse section) is placed against the other. When the two tendinous extremities of a muscle whose form

is symmetrical or nearly so, are placed against the electrodes, the deflection of the needle of the galvanometer is but slight; and the same is the case with two transverse sections taken at equal distances from the two ends of the muscle, and also with two points of the longitudinal section which are equally distant from the middle of its length. But if the two points of the longitudinal section applied to the electrodes be not equally distant from the centre of the muscle, then the point which is nearest to the centre is positive to the one which is nearest to the end; and, in like manner, when the different parts of the transverse section are tested in regard to each other, the points lying nearest the surface of the muscle are found to be positive to those nearest its interior. The intensity of the current, however, between any two points in the *same* section—whether transverse or longitudinal—is always incomparably less than that of the currents which are obtained between two points in *different* sections, one in the longitudinal and the other in the transverse. These results may be obtained, not merely with the entire Muscle, but with insulated portions of it; and even, as we are assured by M. du Bois-Reymond, with a single primitive fasciculus. Hence there appear to be good grounds for believing that every integral part of the muscular substance is a centre of electro-motor action, containing within itself positive and negative elements, arranged, as we have already seen in the case of the nerves (§ 453), in a dipolar series — + + —, — + + —. And further, that the current shown by the entire muscle when made to form part of a circuit is a *derived* current, produced by incomparably more intense currents circulating in the interior of the muscle around these ultimate particles; varying in intensity according to the mode in which these particles are arranged, but usually increasing both with the length and thickness of the muscle.

655. That a change in the electric state of a Muscle takes-place in the act of contraction, had been ascertained by the experiments of Prof. Matteucci;* but as he was only able to detect this by the galvanoscopic frog (the galvanometer which he employed not giving unquestionable indications of it), he was not able to determine its nature with accuracy. This has been accomplished, however, by M. du Bois-Reymond; who has shown that during contraction the muscular current is not increased (as supposed by Matteucci), but is diminished and even reduced to zero. In order to exhibit this phenomenon satisfactorily, it is found advantageous to cause the muscle to contract powerfully or uninterruptedly for as long a time as possible, that is, to *tetanize* it; and this may be effected by acting violently on its nerve by heat, chemical agents, or a succession of electric shocks; or by poisoning the animal with strychnia. In whatever mode the tetanized state is induced, the same result follows;—the needle of the galvanometer passes-over to the negative side. This, however, does not indicate (as might be at first supposed) the development of a new current during the contraction, in a direction opposite to that which prevails during rest; but, according to M. du Bois-Reymond, it is the consequence of the 'secondary polarity'† which is evolved in the platinum

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* See his successive Memoirs in "Philos. Transact." for 1845, 1847, and 1850.

† When the electromotor body is removed, and the two electrodes (platinum plates immersed in a saturated solution of common salt) are connected by some imperfectly conducting body, a secondary current is manifested in the reverse direction to the first,

electrodes, as soon as the muscular current is diminished; the needle passing from the positive to the negative side, as soon as the current of the secondary polarity becomes more powerful than the original muscular current. This negative deflection of the needle at the moment of contraction, is always proportionate to the actual intensity of the current of the muscle while at rest; and it ceases as soon as the tetanic contraction ceases, after which the muscular current gradually recovers its previous intensity.—Dr. Radcliffe* has offered a different explanation of the phenomena, and has endeavoured to show that "the primary electrical condition of living muscle," as well as of living nerve "during the state of inaction, is that of *statical* electricity," and that the muscular current and nerve current which may pass from the muscle or nerve during the state of inaction are only secondary phenomena. He regards the absence of indications of electricity during the contraction of muscle as simply due to a discharge of the natural statical electricity resident in the muscle, the presence of which had previously maintained the muscle in an elongated state. It appears, however, certain that the contraction of a muscle is attended with *a marked diminution of its electromotive power*; a fact which seems to harmonize well with the general views already adverted-to in regard to the 'Correlation of Forces;' the changes which operate to produce disturbance of electric equilibrium whilst the muscle is at rest, being concerned in the development of motor power when it is thrown into contraction. This alteration has been demonstrated by M. du Bois-Reymond in the living animal, after the following manner. The two feet of a live frog were immersed in the two connecting vessels, but one of the legs was paralyzed by division of its sciatic plexus; the muscular currents of the muscles of the two limbs neutralized each other, so long as they remained at rest; but upon the frog being poisoned with strychnia, so that tetanic convulsions occurred in one limb whilst the other remained motionless, the current in the former limb was weakened, whilst that of the other remained unaffected, and a deflection of the needle took place, indicating an upward current in the paralyzed limb and a downward current in the tetanized one. The same thing may be shown in the Human subject, by dipping the forefingers of the two hands into the two conducting vessels connected with the galvanometer, so that the two arms are included in opposite directions in the circuit; when if, after the needle (which usually undergoes a temporary disturbance on their first immersion) has come to a state of rest, all the muscles of one of the arms be strongly and permanently contracted, so as to give them the greatest possible tension without changing the position of the arm, the needle is instantly deflected, always indicating a current from the hand to the shoulder, that is, an *upward* current in the contracted arm. Hence,

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the needle being deflected to the other side; this is caused by the electro-chemical reaction of the substances which the current of animal electricity has evolved on the platinum plates by means of its electrolytic action; and its occurrence is often a useful and valuable confirmation of the first result, as showing that the primary deflection really was the consequence of the presence of an electromotor. When the electromotive action, moreover, is very weak, it may be made more evident by reversing the position of the electromotor, without first replacing the connecter; so that the action which it will then exert in the reverse direction, will be strengthened by the secondary current developed by the previous action.

* In his "Lectures on Epilepsy, Pain, Paralysis, and certain other Disorders of the Nervous System," 1864.

according to the explanation just given, the contracted arm plays the part of the negative metal in the circuit, in regard to the arm whose muscles remain in the state of relaxation, showing that the normal current will be a downward one.—This change, however, is so extremely slight, that a very delicate galvanometer is requisite to render it perceptible. Its intensity depends very much on the muscular energy of the experimenter; and even the greater power which the right arm usually possesses becomes perceptible in the greater deflection of the needle when it is put in action.*

656. The contractility of the muscles may be called into play either directly by stimuli applied to the tissue itself, or indirectly by agents exciting the motor nerves. The contraction which follows in the latter instance is termed by Schiff neuro-muscular, and in the striated muscles is sudden, general, and energetic; but when mechanical irritation is directly applied to a muscle the tissue itself responds to the stimulus, producing what Schiff has termed idio-muscular contraction. It may be observed in the manner first described by Dr. Stokes† by percussing the pectoralis muscle of emaciated patients, or by drawing the back of a knife across a muscle after all signs of irritability on the application of stimuli to the motor nerve have ceased; and presents itself as a swelling or intumescence a few lines broad and high, but varying with the strength of the blow, lasting for four or five seconds, and slowly disappearing. A further phenomenon has been noticed in the same muscles by Auerbach‡ after an energetic blow; namely, a wave or undulating contraction, proceeding from either side of the local intumescence of Schiff, and propagating itself to the extremity of the muscle at the rate of about eighteen inches per second. The breadth of the waves is about a quarter of an inch at their base, and they gradually die out as they spread from the point struck. It is doubtful whether both of these appearances are not due simply to a prolonged contraction of the muscle, resulting from exhaustion of its contractility at the excited spot. Sudden variations of temperature induce persistent contraction of muscular tissue; thus the legs of a frog, dipped into water at a temperature either as high as 130° or as low as 25° Fahr., become tetanized. As regards chemical agents, some appear to act with equal energy in producing contraction, whether applied to the muscle or to the motor nerve, as solutions of potash and soda; others, as creosote, alcohol, pure lactic acid, and glycerine, act on the muscle through the nerve, but possess little stimulating power when directly applied to the muscle; and others again excite energetic contraction when made to act immediately on the muscle, but scarcely operate through the nerve, as sulphate of copper and ammonia.§

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* Of this very remarkable experiment, which was first made by M. du Bois-Reymond, the Author has himself (through that gentleman's kindness) been a witness; and he cannot entertain the least doubt as to the *genuineness* of the phenomenon.—The success of M. du Bois-Reymond in these and similar investigations, is doubtless due in great part to the marvellous sensitiveness of the galvanometer he employs, the coils of which consist of *three miles* of wire, as well as to the perfection of the various arrangements by which he is enabled to avoid or eliminate sources of error; but it must be attributed in great part also to the philosophic method on which his inquiries are planned, and to the skill and perseverance with which they are carried-out.

† "On Diseases of the Chest," p. 397.

‡ "Abhand. der Schleswig Gesells.," 1861, p. 294.

§ See Dr. Duffin's paper 'On Muscular Contraction,' in Beale's "Archives of Medicine," vol. iii. p. 147; and Kühne in "Archiv f. Anat. und Physiologie," 1859, p. 213.

657. The contractions of the Heart present some differences from those of ordinary striated muscular tissue, probably depending upon the peculiar arrangement of its fibres, whereby the contraction of one set gives a mechanical stimulation to others; for the muscular substance of a large part of the organ is thrown into rapid and energetic contraction by a stimulus applied at any one point, and this contraction is speedily followed by relaxation, which is again succeeded by a number of alternating contractions and relaxations. On the other hand, if we apply a similar irritation to a portion of non-striated fibre, as that of the Intestinal Canal, the fasciculus which is stimulated will contract less suddenly, but ultimately to a greater amount; its relaxation will be less speedy, and before it takes place, other fasciculi in the neighbourhood begin to contract; their contraction propagates itself to others, and so on. In this manner consecutive contractions and relaxations may be produced through a considerable part of the canal by a single prick with a scalpel. Again, in the muscular structure of the Bladder and Uterus (when the latter is fully developed), direct irritation excites immediate and powerful contractions, which extend beyond the fasciculus actually irritated, and produce a great degree of shortening; but they do not alternate in the healthy state with any rapid and decided elongation. Similar phenomena may be observed on irritation of the smaller arteries.—The effects of electrical stimulation applied to the muscles themselves are very similar; but it is more difficult to confine the irritation to particular fasciculi of a voluntary muscle, and more easy to throw the whole mass into contraction at once by the transmission of a slight charge through it; and on certain forms of the non-striated fibre the electric stimulus produces effects more decided than can be evoked in any other way. The difference in the endowments of the two kinds of tissue is particularly well seen when they are subjected to the magneto-galvanic apparatus, which transmits a rapid succession of slight electric shocks; for these in the striated muscles immediately excite a state of rigid contraction, which lasts as long as the stimulus is transmitted, but ceases immediately that it is withdrawn; whilst in the non-striated fibres the contraction is slowly excited, sometimes alternates with rest, and continues for a time after the electric discharges have ceased. Of this form of contractility, the muscular coats of the smaller arteries afford a particularly good example; for they may be made to contract by the magneto-galvanic apparatus until they become quite impervious to blood; and yet the contraction neither takes place immediately upon the application of the stimulus, nor does it give place to relaxation directly that it is intermitted.*

658. On the other hand, when the Stimuli which excite muscular contractility are applied to the nerves which supply any muscle composed of striated fibre (the heart only excepted), they produce a simultaneous contraction in the whole muscle, the effect of the stimulus being at once exerted upon every part of it. In order to obtain the full contraction of a muscle by irritation applied to the nerves, it is requisite that the stimulus should be applied for a certain length of time; thus Budge† found that when an electric current was passed through the cervical region of the

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* See Prof. Weber's researches on this subject in Wagner's "Handwörterbuch der Physiologie," Art. 'Muskelbewegung,' and "Müller's Archiv," 1847, band ii.

† "Physiologie," 1862, p. 650.

spinal cord of a rabbit for the space of half a second, the pupil dilated about one-sixth of an inch; but on continuing the application for three seconds, dilatation occurred to the extent of nearly one-third of an inch. In all cases relaxation speedily alternates with contraction, unless the operation of the stimulus be continued—as when an electric current is propagated without intermission along the nerve-trunks—in which case the contraction lasts as long as the stimulus is continuously applied, but ceases as soon as it is withdrawn. The singular "inhibitory" effects produced by irritation of some nerves, as the pneumogastric and splanchnic, have already (§§ 74, 216) been alluded-to; but further experiments are still required before it can be admitted that any nerve can really transmit a "stimulus to relaxation" on the part of the muscle to which it is distributed.

659. The general fact that relaxation alternates with contraction at no long intervals, is most evident in the rhythmical movements of the Heart* and in the peristaltic action of the Intestinal Canal; since in these parts the whole or a large proportion of the fibres seem to contract together, and then shortly relax. But this is probably no less true of the individual fibres of those muscles which are kept in contraction by a stimulus transmitted through their nerves; since none of them appear, under ordinary circumstances at least, to remain in a contracted state for any length of time, a constant interchange of condition taking place among the fibres, some contracting while others are relaxing, and *vice versâ*. It is difficult to speak with confidence, however, in regard to the condition of the individual fibres of a muscle that is thrown into a state of *continued spasmodic* contraction. Whether the individual fibres in such instances maintain a state of contraction without intermission, or whether the contraction of the entire muscle is kept-up by a continual interchange of the fibres actually engaged, is a very curious subject for inquiry.

660. Muscles do not lose their Irritability immediately on the *general death* of the system, which must be considered as taking place when the circulation ceases without the power of renewal; in cold-blooded animals it is retained much longer after this period than in the higher Vertebrata, in some of which it disappears within an hour. The muscles of young animals generally retain their irritability for a longer time than those of adults; on the other hand, those of Birds lose their irritability sooner than those of Mammalia. Hence, as a general rule, the duration of the irritability is inversely as the amount of respiration. From experiments on the bodies of executed criminals who were previously in good health,

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* Some curious rhythmical movements have been observed by M. Brown-Séquard ("Gaz. Méd.," 1849) in the diaphragm, in the intercostals, and in some of the muscles of locomotion, both after death and after section of their nerves during life. These movements could not be in any way dependent upon reflex action, because they took place when the muscles were completely cut off from the nervous centres, sometimes to the number of from 5 to 20 in a minute, and for as long as a quarter of an hour after death; and occasionally recurred in living animals for many months afterwards, especially when the respiration was impeded and the circulation hurried. Of a similar nature are the vibratory movements of the muscles of the tongue witnessed by Schiff after section of the Hypoglossals ("Physiologie," 1859, p. 177); and we may perhaps refer to the same category the trembling movements of the hands and head in old age, in certain forms of paralysis, and in habitual drunkards and smokers. All these cases furnish evidence of a tendency to rhythmical movements in the muscles themselves, altogether independent of the excitement to action which they receive through the nervous system.

Nysten ascertained that in the Human subject the irritability of the several muscular structures disappears in the following time and order:—The left ventricle of the heart first, the intestinal canal at the end of 45 or 55 minutes, the urinary bladder nearly at the same time, the right ventricle after the lapse of an hour; the œsophagus at the expiration of an hour and a half, the iris a quarter of an hour later; the muscles of animal life somewhat later; and lastly, the auricles of the heart, especially the right, which in one instance contracted under the influence of galvanism 16½ hours after death. It will be presently shown that the departure of the irritability is essentially dependent upon the cessation of the circulation, and that it may be prevented from disappearing, and may even be recalled after it has ceased to manifest itself, by transmitting a current of arterial blood through the muscles.

661. Muscular Irritability is deadened by many substances, and especially by those which have a narcotic or sedative action on the nervous system. In carbonic acid gas, hydrogen, carbonic oxide, or sulphurous acid gas, muscles contract very feebly, or not at all, when stimulated; whilst in oxygen they retain their irritability longer than usual. Narcotic substances, such as a watery solution of opium, when applied directly to the muscles, have an immediate and powerful effect in diminishing or even destroying their irritability; this effect is also produced, though in a less powerful degree, by injecting these substances into the blood. In the same manner venous blood charged with carbonic acid, and deficient in oxygen, has the effect of a poison upon the muscles, diminishing their irritability, when it continues to circulate through them, to such a degree that they sometimes lose it almost as soon as the circulation ceases, as is seen in those who have died from gradual and therefore prolonged asphyxia. The unfavourable influence of venous blood is also shown in the Morbus Cœruleus, patients affected with which are incapable of any considerable muscular exertion. Although most of the stimuli which occasion the contraction of muscles, when directly applied to their fibres, operate also when applied to their motor nerves, the same does not hold good in regard to those agents which diminish irritability. It is a fact of some importance in relation to the disputed question of the connection of muscular irritability with the nervous system, that when, by the application of narcotic substances to the nerves, their vital properties are destroyed, the irritability of the muscle may remain for some time longer, showing that the latter must be independent of the former.—The effects produced by the Woorara and Upas Antiar poisons in this respect are exceedingly curious, and have been carefully studied by Bernard* and others. Woorara (and, according to Kölliker, Conia also) appears to act directly upon the motor nerves, whilst Cyanide of Potassium and the poison of the Upas Antiar abolish the irritability of the muscular tissue itself. The evidence given by Bernard in proof of these statements is very satisfactory, for he has shown that the cause of death after the administration of a sufficient dose of Woorara is the cessation of the respiratory movements owing to paralysis of the motor nerves; for not only has it been proved by v. Bezold that by this agent the rapidity of the conduction of stimuli

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* See his Lecture in "Med. Times and Gazette," 1860, vol. ii.; also A. v. Bezold in "Monats Bericht der Berlin. Akad.," 1859; and Martin-Magron and Buisson in "Journal de la Physiologie," 1860.

through the motor nerves is greatly reduced and ultimately abolished, but it is certain that perfect recovery may take place if artificial respiration be maintained for a sufficient length of time to enable the poison to be eliminated from the system or decomposed within it; whilst in fœtuses, and during the earlier stages of existence of fishes and other animals that are not directly dependent upon muscular movements for the aeration of their blood, this being accomplished by the umbilical vesicle, little or no injurious effect is experienced, the animals continuing to swim about in a watery solution of the poison without apparent inconvenience. That the sensory nerves are not affected seems to be proved by the experiments of Kölliker and Funke, who observed that reflex actions could readily be excited in parts kept free by the ligature of their vessels from the circulation of poisoned blood, on pricking or pinching the skin of parts poisoned by the admission of blood containing Woorara. The influence of the poison seems to be first felt by the peripheral extremities of the nerves, and its paralyzing effect gradually extends centripetally through the trunks of the nerves.*—An additional argument may be mentioned in favour of the essential independency of muscular irritability, in the circumstance that, although spontaneous movements occur in the muscles of embryos, the muscles cannot, in the earlier periods of fœtal life, be incited to contract by stimuli directly applied to their nerves.—Dr. Harless† again found that when the Nervous system had been rendered, by the inhalation of ether, utterly incapable of conveying a galvanic stimulus applied either to the nervous centres or to the nerve-trunks, the same stimulus applied directly to the muscles would immediately throw them into powerful contraction. Various other experimenters have shown that when the nerves supplying the muscles of a limb are divided and the animals are allowed to live, excitants applied to the nerves beyond the point of division fail to produce muscular contraction long before they cease to do so when applied to the muscles themselves. Hence it is obvious that the activity of the Nervous system is not essential to the manifestation of the characteristic endowment of the Muscular.

662. We find, however, that sudden and severe injuries of the Nervous centres have power to *impair*, directly and instantaneously, or even to *destroy* the contractility of the whole Muscular system; so that death immediately results, and no irritability subsequently remains. It is in this manner that the *sudden* destruction of the brain and spinal cord, especially of the latter, occasions the immediate cessation of the heart's action, though they may be *gradually* removed without any considerable effect upon it. Severe concussion has the same effect; hence the syncope which *immediately* displays itself. It is sometimes an important question in forensic medicine, whether an individual who has died from the effects of a blow upon the head, could have moved from the place where the blow was inflicted. If there be found, as is frequently the case, no sensible disorganization of the brain, the death must be attributed to the concussion, and must have been in that case *immediate*. If, on the other

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* In Funke's "Physiologie" (4th edit., 1863) a very long section is devoted to the action of Woorara, which he concludes by observing that the results of experiments with this poison do not enable us to decide with absolute certainty on the existence of an independent muscular irritability. Upon the whole, however, they appear in his opinion to favour that view.

† "Müller's Archiv," 1847, band ii.

hand, effusion of blood has taken place within the cranium to any considerable extent, it is probable that the first effects of the blow were in some degree recovered-from, and that the circulation was re-established. It is not essential, however, that the impression should be primarily made upon the Cerebro-Spinal system. The well-known fact of sudden death not unfrequently resulting from a blow on the stomach, especially after a full meal, without any perceptible lesion of the viscera, clearly indicates that an impression upon the widely-spread cœliac plexus of Sympathetic nerves (which will be much more extensively communicated to them when the stomach is full than when it is empty) may cause the immediate cessation of the heart's action, in the same manner as a violent injury of the brain or spinal cord. In all these cases *the whole vitality* of the system appears to be destroyed at once; for the processes which would otherwise succeed to the injury, and which after other kinds of death less sudden in their character, produce evident changes in the part of the surface that has immediately received it, are here entirely prevented. An instance is on record in which a criminal under sentence of death determined to anticipate the law by self-destruction. Having no other means of accomplishing his purpose, he stooped his head and ran violently against the wall of his cell; he immediately fell dead, and *no mark* of contusion showed itself on his forehead. The same absence of the usual results is to be noticed in the case of blows on the stomach. The influence of severe impressions on the nervous system in *diminishing*, when it does not altogether destroy, muscular irritability, is well seen in the operation of severe injuries affecting vital organs, or extending over a large part of the surface, in depressing the heart's action; to which attention has already been directed (§ 216).

663. From a general consideration of the phenomena of Irritability, we can scarcely do otherwise than acquiesce fully in the doctrine of Haller, which involves no hypothesis, and which is perfectly conformable to the analogy of other departments of Physiology. He regarded every part of the body which is endowed with irritability as possessing that property in and by itself; but considered that the property is subjected to excitement and control from the nervous system, the agency of which is one of the stimuli that can call it into operation. It may be desirable briefly to sum up the facts by which this doctrine is supported. 1. The existence in vegetables of irritable tissues, which are excited to contraction by stimuli directly applied to themselves, and which can be in no way dependent upon or influenced by a nervous system. 2. The existence in animals of a form of muscular tissue which is especially connected with the maintenance of the organic functions, and which is much more readily excited to action by direct stimulation than it is by nervous agency. 3. The fact that by the agency of these the organic functions may go on (so long as their requisite conditions are supplied) after the removal of the nervous centres (of the Cerebro-Spinal system at least), and when these were never present; rendering it next to certain that their ordinary operations are not dependent upon any stimuli received through the nerves, but upon those directly applied to themselves. 4. The persistence of irritability in muscles, for some time after the nerves have ceased to be able to convey to them the effects of stimuli: this is constantly seen in regard to the Sympathetic system of nerves, and the muscles of organic

life upon which they operate; and it is shown, by the agency of narcotics, to be true also with respect to the Cerebro-Spinal system and the muscles of Animal life. 5. The continuance of irritability in the muscles after their complete isolation from the nervous centres, so long as their nutrition is unimpaired; and the effects of frequent exercise in preventing the impairment of the nutrition and the loss of irritability. 6. The recovery of the irritability of muscles, when isolated from the nervous centres, after it has been exhausted by repeated stimulation: this also depends upon the healthy performance of the nutritive actions. 7. The existence of certain poisons which appear to possess a directly depressing effect on the conducting power of motor nerves, without exerting any influence upon the irritability of muscles. 8. The existence of certain tracts of muscular tissue, as those, for instance, of the walls of the umbilical vessels, which according to Virchow, whilst possessing considerable irritability, show no trace of nervous tissue. In the words of Dr. Alison, then, "the only ascertained final cause of all endowments bestowed on nerves in relation to muscles, in the living body, appears to be not to make muscles irritable, but to subject their irritability in different ways to the dominion of the acts and feelings of the mind,"—to its volitions, emotions, and instinctive determinations.*

664. There can be no question that the condition most essential to the maintenance of muscular contractility is an adequate supply of arterial blood. It is well known that when a ligature is applied to a large arterial trunk in the Human subject, there is not only a deficiency of sensibility in the surface, but also a partial or complete suspension of muscular power, until the collateral circulation is established. The same result has been constantly attained in experiments upon the lower animals; the contractility of the muscle being impaired or altogether extinguished when the flow of blood into it was arrested, and being recovered again when the supply of blood was restored.—The various experiments of M. Brown-Séquard† on this subject are still more satisfactory, as showing that the contractility of muscles, whether of the striated or smooth variety, may be *restored* by the transmission of aerated blood through them, after it has entirely ceased, and has even given place to cadaveric rigidity. Thus he found that when he connected the aorta and vena cava of the body of a rabbit which had been some time dead, and in which the cadaveric rigidity had already manifested itself for between ten and twenty minutes, with the corresponding vessels of a living rabbit, so as to re-establish the circulation in the lower extremities, the rigidity disappeared in from six to ten minutes, and in two or three minutes afterwards the muscles contracted on being stimulated. He subsequently made similar experiments upon the muscles of a decapitated criminal; the hand being selected as a convenient part for the purpose. It was not until nearly 12½ hours after death that all traces of irritability had left the muscles, and the injection was not commenced until 45 minutes after this, cadaveric rigidity having appeared in the

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* For a good *resumé* of the arguments for and against the theory of independent irritability in muscles, see a paper by Dr. H. N. Maclaurin in "Edinb. Med. Journal," July, 1863.

† See "Gazette Médicale," 1851, Nos. 24 and 27; and "Journal de la Physiologie," 1858, vol. i. pp. 95-353-729.

interval. About half a pound of human blood which had been defibrinated and freely exposed to the air so as to acquire the arterial tint, was then injected at intervals for about thirty-five minutes; ten minutes after the last injection the greater number of the muscles were found to be irritable, and these remained so for two hours, after which the contractility gradually departed, and was succeeded by cadaveric rigidity. The blood which had been injected in an arterialized condition, issued from the vessels quite dark; and as this occurred over and over again, the change of hue could not be attributed to anything else than the reaction between the blood and the tissues.—Similar experiments were made twenty-seven hours after death, upon the muscles of the foot of the same criminal; but with an entirely negative result, save that the blood which was injected returned of a considerably darker hue.—Still more recent experiments have shown that in order that the muscles should retain their elongated condition, it is necessary that they should be supplied with arterial blood, the passage of venous blood through their capillaries immediately inducing contraction. This was remarkably exemplified in an experiment made by M. Brown-Séquard upon a pregnant rabbit, in which the injection of venous blood into the uterine vessels immediately excited the organ to contract, and caused the expulsion of two or three fœtuses, whilst on injecting arterial blood all signs of contraction immediately passed off. It is doubtful whether the stimulus to contraction in these cases is the presence of carbonic acid, or whether, as Dr. Radcliffe* supposes, it is not rather to be attributed to a deficiency of oxygen, the readmission of which restores the vital properties of the muscle and induces its elongation. The latter view is certainly supported by the violent convulsions which occur in animals that are bled to death; and even the convulsions which are witnessed in asphyxia, when the contracted state of the small arteries (§ 299) and the consequent diminished transmission of blood through the capillaries are borne in mind, are not unfavourable to it. Dr. Radcliffe has adduced the interesting experiments of Dr. George Harley† upon the influence of the addition of strychnia and brucia to blood, as essentially confirmatory of his view; since these poisons prevent the blood from absorbing oxygen, and their action may thus be said to be equivalent to a copious loss of blood.

665. Whilst the Irritability of Muscles is gradually departing after death, it not unfrequently shows itself under a peculiar form; for, instead of producing sudden contractions, speedily followed by relaxation, the application of Stimuli then occasions slow and somewhat prolonged contractions, the relaxation after which is tardy. This form of contraction is seldom seen in adult Mammalia, except (as will be presently shown) when death has taken place from certain diseases that have a special influence on the blood and muscular system; but it is stated by M. Brown-Séquard‡ to present itself more constantly in young animals, and to be (so to speak) an exaggeration of the ordinary *modus operandi* of their muscles, which during life are much more slowly thrown into contraction by mechanical stimuli than they are in adults.—The most remarkable

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* In whose work "On Epileptic and other Convulsive Affections of the Nervous System" (3rd edit., 1861), much original and interesting information on the subject of muscular contractility will be found.

† See "Lancet," 1856.

‡ "Gazette Médicale," December 22, 1849.

manifestations of it yet observed, however, have been witnessed after death from Cholera and Yellow Fever; for in these cases the muscular contractions, though capable of being excited by mechanical stimulation applied to the muscles themselves, are frequently spontaneous, and sometimes give rise to movements strongly resembling the ordinary actions of the living state. In regard to the occurrence of this phenomenon after death from yellow fever, several interesting observations have been recorded by Dr. Bennet Dowler of New Orleans.* In one case, the subject of which was an Irishman, aged twenty-eight, the following series of movements took place spontaneously not long after the cessation of the respiration: first the left hand was carried by a regular motion to the throat, and then to the crown of the head; the right arm followed the same route on the right side; the left arm was then carried back to the throat, and thence to the breast, reversing all its original motions, and finally the right hand and arm did exactly the same. Similar phenomena have been described by Mr. N. B. Ward, Mr. Helps, and Mr. Barlow† as occurring in the bodies of cholera patients. Many circumstances indicate that these movements were due to the inherent contractility of the muscles, and were not in any degree dependent upon the operation of the nervous system; and Dr. Dowler proved experimentally, by completely separating limbs which exhibited these movements from the trunk of the body, that the influence of the nervous system was not in any degree essential to their production.

666. The *Rigor mortis*, or Cadaveric rigidity of the muscles, begins immediately after all indications of irritability have departed, but before any putrefactive change has commenced. The supervention of the rigidity is not usually prolonged much beyond seven hours, though a tetanic state at first sight resembling it may occasionally be observed to occur instantly after death from some peculiar conditions of the nervous and muscular systems at the moment. In other instances twenty or even thirty hours may elapse before it shows itself. Its general duration is from twenty-four to thirty-six hours, but it may pass off much more rapidly, or it may be prolonged to four or six days. It first affects the neck and lower jaw, then the trunk, then the upper extremity, and finally, the muscles of the lower extremities. In its departure, which is immediately followed by decomposition, the same order is followed. It is remarkable that it is equally intense in muscles which have been paralyzed by Hemiplegia, or whose nerves have been previously severed, provided that no considerable change has taken place in their nutrition. All circumstances which tend to exhaust or depress the irritability of the muscles, such as death by slow and wasting disease, violent muscular exertion immediately before death, or powerful electrical shocks passed through the motor nerves, induce the early appearance and speedy departure of this state—putrefaction subsequently appearing and progressing rapidly. On the other hand, when the general energy has been retained up to a short period before death, as in persons who die from an accidental cause, or in animals the irritability of whose muscles has been augmented by cold, cadaveric rigidity sets in late and lasts long, and putrefaction also appears late and progresses slowly. Muscles deprived of blood by the ligature of their arteries, or by the

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* "Experimental Researches on the Post-mortem Contractility of the Muscles," 1846.

† See Mr. F. Barlow's 'Observations on the Muscular Contractions which occasionally occur after Death from Cholera,' in "Med. Gazette" for 1849-50.

injection of warm water, pass into a state closely analogous to, if not identical with Rigor mortis; and within certain limits their powers can be restored by the readmission of a current of duly oxygenated or arterial blood.—The condition of the muscles in post-mortem rigidity is in many respects different from that of the contraction which occurs during life. In the former the shortening is persistent and uniform, the elasticity of the tissue is increased, it feels firm and hard, and there are no signs of electrical disturbance. In the latter, on the contrary, there is, as we have seen, a diminution in the amount of elasticity and of firmness, there is evidence of a change in the state of electrical tension (negative variation), and the contraction is intermittent.—Rigor mortis was formerly attributed to the coagulation of the blood, but many facts are opposed to this view. There is some evidence, however, in favour of the opinion of Brucke that it results from the coagulation of a fibrinous material contained in the interfibrillar juices of the muscle; for Kuhne has shown that a spontaneously coagulable substance can be obtained from living muscle by the injection into its vessels of saline or saccharine solutions, which evidently retard the coagulation of this substance; and moreover, whilst the muscles from which this spontaneously coagulable material has been withdrawn, are incapable of passing into the state of Rigor mortis, those which have already become rigid no longer yield up any portion of it to the injected fluids.*

667. It was formerly customary to divide the Muscles into two groups, termed the "voluntary" and "involuntary," corresponding to the "striated" and "non-striated" tissue respectively, but there are various circumstances which show that this system of classification cannot be consistently maintained. It is quite true that all the Muscles of Organic Life may be truly styled 'involuntary;' for although they are capable of being influenced by emotional and ideational states of mind, yet the Will cannot exert any direct influence upon them, only affecting them indirectly by its power of determining these states. But over those Muscles, also ministering to the Organic functions, and doing so in obedience to impulses purely automatic, which are called into action by the Cranio-Spinal nerves, the Will, as we have seen, exerts some power; and such, therefore, cannot be properly regarded as involuntary, since the Will can influence their state; whilst they are far from being truly voluntary, since the Will cannot control their tendency to automatic action beyond a certain limited amount (§ 276). On the other hand, every one of the Muscles usually styled voluntary, because ordinarily called into action by the Will, is liable to be thrown into action involuntarily; either by an Excito-motor stimulus, as in tetanic convulsions, or by Consensual action, as in tickling, or Emotionally, as in laughter or rage, or simply Ideationally, as in somnambulism and analogous states. Hence although there are certain groups of muscles which are more frequently acted-on by the Will than by any other impulse, and certain others which are more frequently played-on by the Emotions, and so-on, it becomes obvious that every muscle called into contraction by the Cranio-Spinal nervous system, is capable of receiving its stimulus to

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* For further information respecting the relations between rigor mortis, the irritability of the muscle, and the appearance of putrefaction, see the Croonian Lecture for 1861, delivered by M. Brown-Séquard before the Royal Society, in the "Proceedings of the Royal Society," vol. xi. p. 204.

movement from *any* of these sources; the nerve-force transmitted along the motor-fibres, being issued either from the Spinal Cord, from the Sensory Ganglia, or from the Cerebrum, as the case may be, but being in its nature and effects the same in every instance.

668. The grouping or combination of Muscular actions, which takes place in almost every movement of one part of the body upon another, must be attributed, not to any peculiar sympathy among the Muscles themselves, but to the mode in which they are acted-on by the Nervous Centres. This is most obviously the case with regard to those of the primarily-automatic class; but it can scarcely be doubtful as to those of the secondarily-automatic kind (§ 534), such as walking, which, though at first directed by the Will, come by habit to be performed under conditions essentially the same with the preceding; and when it is borne in mind that even in voluntary movements the Will cannot single-out any one muscle from the group with which it usually cooperates, so as to throw this into separate contraction, but is limited to determining the result (§ 528), it seems pretty obvious that even here the grouping is effected by the endowments of those Automatic centres from which all the motor impulses immediately proceed to the muscles, and not by Cerebral agency. In fact, the whole process by which we acquire the power of adapting our muscular actions to the performance of some new kind of movement,—as in the case of an infant learning to walk, a child learning to write, an artizan learning some occupation which requires nice manipulation, a musical performer learning a new instrument, and so on,—is found, when attentively studied, to indicate that the Will is far from having that direct and immediate control over the contractions of the Muscles, which it is commonly reputed to possess; and that the operation really consists in the gradual establishment of a new grouping of the separate actions, in virtue of which, the stimulus of a Volitional determination, acting under the guidance of the muscular sensations (§ 524), henceforth calls into contraction the group of muscles whose agency is competent to carry that determination into effect. For however amenable any set of muscles (as those of the arm and hand) may have become to the direction of the Will, in any operations which they have been previously accustomed to perform, it is only after considerable practice that they can be trained to any method of combined action which is entirely new to them; and even if we attempt to bring our anatomical knowledge into use for such a purpose, by mentally fixing upon certain muscles whose action we wish to intensify and to associate with those of others, we find that such a method of proceeding affords no assistance whatever, but rather tends to impede our progress, by drawing-off the attention from the 'guiding sensations' (visual, muscular, &c.), which are the only regulators that can be depended-upon for determining the due performance of the volitional mandate.—Hence we are led by these considerations, as by those stated in the preceding paragraph, to the conclusion, that the agency which directly affects the muscles is of the same kind, and that it operates under the same instrumental conditions, whatever be the primal source of the motor power. And in watching the gradual acquirement of the capacity for different kinds of movement, during the periods of Infancy and Childhood in the Human subject, we find every-

thing to confirm this conclusion. For it becomes obvious that the acquirement of Voluntary power over the movements of the *limbs*, is just as gradual as it is over the direction of the *thoughts*; all the activity of the *body*, as well as of the *mind*, being in the first instance automatic; and the Will progressively extending its domination over the former, as over the latter, until it brings under its control all those muscular movements which are not immediately required for the conservation of the body, and turns them to its own uses.*

2. *Of the Symmetry and Harmony of Muscular Movements.*

669. It might have been not unreasonably supposed, *à priori*, that those muscles would have been most readily put into simultaneous contraction which correspond to each other on the two sides of the body; in other words, that *symmetrical* movements would be those most readily performed. Such, however, is by no means the case; for in many of our most familiar actions we consentaneously exert different muscles on the two sides of the body. This is nowhere more clearly shown than in the various movements that are required for the performance of the different acts of locomotion, and which may here be briefly noticed. In order to maintain the body in the erect posture, simple as the effort appears, the concurrent action of many muscles is required, as is clearly shown not only by the numerous and futile trials made by children before the power of balancing is acquired, but by the impossibility of placing a dead body in this position without support. In *standing*, the legs are more or less extended; and the weight of the trunk is transmitted through the femora and the tibiæ and fibulæ to the astragali. These, with the other tarsal and metatarsal bones, form an elastic arch on either side, which, whilst allowing the great superincumbent pressure to be borne with ease, enables each foot to accommodate itself to irregularities of the surface of the ground, and at the same time breaks the shock or jar which would otherwise be experienced in the various movements of walking, running, or leaping. The centre of gravity of the whole body lies, according to Weber, in the promontory of the sacrum; but, according to Meyer, in the canal of the second sacral vertebra. As long as a perpendicular line drawn from this point to the earth drops within the basis formed by the feet, the erect posture can be maintained with comparative ease; if it drop outside that basis, the subject must inevitably fall. The chief

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* The aptitude which is acquired by practice, for the performance of certain actions that were at first accomplished with difficulty, seems to result as much from a structural change which the continual repetition of them occasions in the Muscle, as in the habit which the Nervous system acquires of exciting the movement. Thus almost every person learning to play on a musical instrument, finds a difficulty in causing the two shorter fingers to move independently of each other and of the rest; this is particularly the case in regard to the ring-finger. Any one may satisfy himself of the difficulty, by laying the palm of the hand flat on a table, and raising one finger after the other, when it will be found that the ring-finger can scarcely be lifted without disturbing the rest,—evidently from the difficulty of detaching the action of the portion of the *extensor communis digitorum*, by which the movement is produced, from that of the remainder of the muscle. Yet to the practised musician, the command of the Will over all the fingers becomes nearly alike; and it can scarcely be doubted that some change in the structure of the muscle, or a new development of its nerve-fibres, takes place, which favours the isolated operation of its several divisions.

muscles called into play in the standing position are those which keep the head vertical on the spinal column, as the recti, obliqui, sternomastoids, splenii, complexus, &c., the extensors of the spine, as the erectores spinæ and their prolongations, and the extensors of the thigh and leg; but the opposite muscles are, as a sailor would express it, 'taut' and ready to contract instantaneously and unconsciously on the slightest indication of loss of equilibrium.

670. *Walking.*—In this movement the body, supported in a nearly vertical position, alternately rests on the right and left leg; the limb upon which it does not rest swinging forward, like a pendulum, in a remarkably regular manner, just sufficiently bent to avoid contact with the ground. The inclination of the trunk of the body from the perpendicular, which is very slight in slow walking, always increases with the rapidity of the step. If we examine the successive movements which occur in making two steps, it will be found that if the subject be standing firmly with the left leg in advance, the first act consists in raising the heel of the right foot, which is accomplished by the gastrocnemius and soleus muscles; and the weight of the whole body thus raised is by the simultaneous contraction of the psoas and iliacus muscles of the left leg thrown over to the left side, resting for an instant upon the left foot. At this period all the extensors of the left leg, the glutæi, the quadriceps extensor femoris, the tibialis anticus, &c., are powerfully contracted. The right leg, the toe of which is the last part which touches the ground, now swings forward, the knee and hip joints being just sufficiently bent to enable the foot to clear accidental irregularities of the surface. Lastly, the right heel is planted on the ground in front, and is immediately followed by the whole surface of the foot; but coincidentally with this occur the elevation of the left heel and the throwing over of the weight of the trunk to the right side, which is followed by the swinging forward and implantation of the left foot, and so on alternately. The weight of the legs in the act of swinging forward has been shown by Weber to be materially diminished by the pressure exerted by the atmosphere in retaining the head of the femur in the acetabulum. The ordinary rate of movement in walking for each person is to an important extent regulated by the length of the leg, and the consequent duration of its pendulum-like oscillation. Various compensatory movements in walking occur in order to maintain the equipoise of the body; amongst the most important of these are the movements of the arms, for whilst the right leg is swinging forwards, the twisting of the trunk which occurs at this period would bring the right shoulder forwards, but the right arm at this moment swings backwards and the left forwards, and by thus generating a force in the opposite direction neutralizes this tendency. A corresponding compensation takes place when the left leg swings forward, and this is effected by a good walker without any sensible lateral twisting of the trunk.* At the moment that the foremost foot is implanted on the ground, the body sinks a little, but rises again when the impulse is given by the opposite foot leaving the ground. The extent of this undulatory movement is very small, not exceeding 1¼ inch. The number of steps in a given time, or the pace of walking, is partly dependent upon the length of the legs, and partly upon direct muscular effort: the longer the leg, the slower will be the oscil-

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[*] See Bishop in "Cyclop. of Anat. and Phys.," vol. iii. p. 460.

lation; but by planting the foot on the ground when it has only passed through one-half of its natural oscillation, the succession of steps, and consequently the rapidity of progress, can be materially increased, without much effort. In very quick walking almost every muscle in the body is brought into play; the trunk is considerably inclined forwards, partly for the purpose of resisting and compensating for atmospheric pressure, but chiefly to enable the hip-joints to be carried low, thus increasing the extent of ground which can be covered by each step, whilst at the same time the number of steps is greatly increased by muscular effort; the period during which both feet are resting on the ground together being considerably shortened. In an experiment made by Mr. Vasey, the length of whose leg was thirty-four inches, in walking at the rate of four miles an hour, 2000 steps were made every fifteen minutes; the length of each step must therefore have been 2·64 feet, and the time of each step 0·45 second.—Quick walking passes by insensible gradations into *running*, the period in which the body rests upon both feet becoming shorter and shorter, until at length there is a period between successive steps, during which the body moves forward unsupported by either foot. According to Weber, the vertical undulations of the trunk in running vary from 3-4ths to 4-5ths of an inch, the duration of the step from 1-4th to 1-5th of a second, of which time the body swings unsupported in the air 1-10th of a second, the time of descent being 1-15th of a second.—In *leaping*, the extensor muscles are brought into extremely vigorous action, and the act may be accomplished either by the alternate or the simultaneous action of the legs, as seen in the "hop, step, and jump" of children. The essential difference in leaping and running is, that in leaping the body is raised so high from the ground, and for so long a period, that the leg or legs have time to complete their full arc of oscillation, and consequently cover the utmost space of ground possible. The extent of the leap is of course dependent upon the muscular energy of the individual.*

671. Now it is plain that the grouping of the muscular movements in these different instances arises out of its *felt* conformity to the end in view, and that it is regulated by the guiding sensations which indicate to us the progression and balance of the body. The infant, in learning to walk, is prompted by an instinctive tendency to put one foot before the other, as may be noticed at a very early period, when it is first held so as to feel the ground with its feet; and in attempting to balance itself when first left to stand alone, it moves its arms with a like intuitive impulse, not based upon experience. All that experience does, in either case, is to give that precise adjustment to the muscular action, which makes it perfectly conformable to the indications afforded by the muscular sensations. Thus, if we advance each arm with its corresponding leg, we feel that the balance of the body is not nearly as readily maintained, as it is when we advance the arm with the leg of the opposite side; and thus, without any design or voluntary determination on our own parts, the former comes to be our settled habit of action. This kind of adjustment, in the case before us, is by no means limited to the muscles of the limbs; for there

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* The subject of the locomotion of Man has been particularly investigated by the Profrs. Weber, whose work entitled "Mechanik der menschlich. Gehwerkzeuge" (Göttingen, 1836) has been translated in Jourdan's "Encyclopédie Anatomique," tom. ii. See also the Art. 'Motion' by Mr. J. Bishop, in "Cyclop. of Anat. and Physiol.," vol. iii.

is scarcely any muscle of the trunk or head, that is not exerted with some degree of consentaneous energy, however unconsciously to ourselves, in the act of walking. The difficulty which would attend the voluntary harmonization of all these separate actions, is remarkably evinced by the fact, that no mechanist, however ingenious, has ever succeeded in constructing an automaton that should *walk* like Man; the alternate shifting of the centre of gravity from one side to the other, upon so small a base as the human foot affords, simultaneously with the movement in advance, constituting the great difficulty of biped progression. But all this adjustment is effected in our own organisms *for* us, rather than *by* us; the act of harmonization, when once fully mastered, being attended with no effort to ourselves; but the whole series of complex movements being performed in obedience to the simple determination *to walk*, under the automatic guidance of the senses, which instantly reveal to us any imperfection in the performance.—The same view extends itself readily to other combinations of dissimilar and non-symmetrical movements, which are less *natural* to Man, but which may be readily acquired *artificially* if they all harmonize in a common purpose, and are under the guidance of the same set of sensations. Thus, the performer on the Organ uses the several fingers of his two hands to execute as many different movements (in very different positions, it may be) on the 'manual' keys: one of his feet may be on the 'swell' pedal, and the other may be engaged in playing on the 'pedal' keys; but all these diverse actions are harmonized by their relation to the same set of auditory sensations; and if the result be not that which the performer anticipated, an immediate correction is made.

672. It would be easy to multiply instances of the same kind, all illustrative of the general principle, that the facility with which we voluntarily combine different movements is chiefly determined, not by their *symmetrical* character, but by their *conformableness to a common end*, and by the *harmony of their guiding sensations* with reference to that end;* but it will be desirable to dwell particularly on the *Movements of the Eye*, as presenting certain points of peculiar interest, some of which have an important bearing on Surgical practice.—It will be recollected that in the Human Orbit, six muscles for the movements of the eyeball are found; the four Recti, and the two Oblique muscles. The precise actions of these are not easily established by experiment on the lower animals; for in all those which ordinarily maintain the horizontal position, there is an additional muscle, termed the *retractor*, which embraces the whole posterior portion of the globe, and passes-backwards to be attached to the bottom of the orbit.† If the origin and insertion of the four *Recti* muscles be

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* Two simple examples, however, may be cited, of the difficulty which attends the simultaneous performance of movements that are not harmonious. If we attempt to elevate one eyelid whilst we are depressing the other, we find that a considerable effort is required to accomplish the action, although the elevation or depression of both eyelids together is performed with so little effort that we are scarcely conscious of it; and the difficulty is increased if we half-shut both eyes, and then try to close one and to open the other. So if we try to move our two hands as if they were *simultaneously* winding cord *in opposite directions* upon two reels placed in front of us, we shall find ourselves unable to do so without a constant exercise of the attention, and even then but slowly and with difficulty; although the very same movements may be *separately* performed, or both hands may be made thus to move *in the same direction*, with the greatest facility.

† This muscle is most developed in Ruminating animals, which, during their whole

examined, however, no doubt can remain that each of them, acting singly, is capable of causing the globe to revolve in its own direction,—the superior rectus causing the pupil to turn upwards,—the internal rectus causing it to roll towards the nose,—and so on. A very easy and direct application of the laws of mechanics will further make it evident to us, that the combined action of any two of the Recti muscles must cause the pupil to turn in a direction intermediate between the lines of their single action; and that *any* intermediate position may thus be given to the eyeball by these muscles alone. This fact, which has not received the attention it deserves, leads us to perceive that the Oblique muscles *must* have some supplementary function. It may be objected that this is a theoretical statement only; and that there may be some practical obstacle to the performance of diagonal movements by the Recti muscles, which renders the assistance of the Obliques essential for this purpose. But to this it may be replied, that *no single* muscle can direct the ball either downwards and inwards, or upwards and outwards: and that, as we have good reason to believe *these* movements to be effected by the combination of the Recti muscles, there is no reason why *the other* diagonal movements should not also be due to them.—The most probable account of the functions of the *Oblique* muscles of the eye, seems to be that which was long ago suggested by John Hunter, and which has received confirmation from the experiments of Dr. G. Johnson.* It has been just shown that the action of the Recti muscles upon the pupil, is such as to cause it to *revolve* in any given direction: and this is put in force, not merely to alter the range of vision, the head remaining stationary; but also to keep the range of vision the same, and to cause the images of the objects upon which our gaze is fixed, still to fall upon the same parts of the retinæ, by maintaining the position of the eyes when the head is moved upwards, downwards, from side to side, or in any intermediate direction (§ 529). But these muscles are not able to *rotate* the eyeball upon its antero-posterior axis; and such rotation is manifestly necessary to preserve the fixed position of the eyeball, and consequently to keep the image of the object under survey upon the same part of the retina, when the head is inclined sideways, or is bowed towards one shoulder and then towards the other. It appears from the experiments of Dr. G. Johnson, that the action of the Oblique muscles is exactly adapted to produce such a rotation: the Inferior Oblique, in its contraction, causing the eyeball to move upon its antero-posterior axis, in such a manner that a piece of paper, placed at the outer margin of the cornea, passes downwards and then inwards towards the nose; and the Superior Oblique effecting precisely the reverse action, the paper at the outer margin of the cornea passing first upwards

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time of feeding, carry their heads in a dependent position. In most Carnivorous animals, instead of the complete hollow muscular cone (the base inclosing the eyeball, whilst the apex surrounds the optic nerve), which we find in the Ruminants, there are four distinct strips, almost resembling a second set of recti muscles, but deep-seated, and inserted into the posterior instead of the anterior portion of the globe. It is obvious that the actions of these must greatly affect the results of any operations which we may perform upon the other muscles of the Orbit; and, as it is impossible to divide the former, without completely separating the eye from its attachments, we have no means of correcting such results, but by reasoning alone. Experiments upon animals of the order Quadrumana, most nearly allied to Man, would be more satisfactory; as in them, the retractor muscle is almost or entirely absent.

* "Cyclopædia of Anatomy and Physiology," vol. iii. p. 790.

and then inwards. There was not the slightest appearance, in these experiments, of elevation, depression, abduction, or adduction, of the cornea, as a result of the action of the Oblique muscles; all these movements being attributable to the Recti alone.

673. On studying the Voluntary movements of the Eyeballs, we are led to perceive that they are not so much *symmetrical* as *harmonious;* that is to say, the corresponding muscles on the two sides are rarely in action at once; whilst such a harmony or *consent* exists between the actions of the muscles of the two orbits, that they work to one common purpose, namely, the direction of both eyes towards the required object. They may be arranged under two groups; the first comprising those which are alike harmonious and symmetrical; the second including those which are harmonious but not symmetrical. To the *first* group belong the following:—1. *Both* eyeballs are *elevated*, by the contraction of the two Superior Recti—2. *Both* eyeballs are *depressed*, by the conjoint action of the Inferior Recti muscles.—3. *Both* are drawn directly *inwards*, or *inwards* and *downwards*, as when we look at an object placed on or near the nose; this movement is effected by the action of the Internal Recti of the two sides, with or without the Inferior Recti. It is evidently symmetrical, but might seem at first sight not to be harmonious, because the eyes do not move together towards one side or the other; it is, however, really harmonious, since it directs their axes towards the same point.*—Now it is to be observed, with regard to these movements, that we can never effect them in antagonism with each other, or with those of other muscles. We cannot, for example, raise one eye and depress the other; nor can we raise or depress one eye, when we adduct or abduct the other. The explanation of this will be found in the fact, that we can never, by so doing, direct the eyes to the same point.—The harmonious but unsymmetrical movements, forming the *second* class, are those in which the Internal and External Recti of the two sides are made to act together, either alone, or in conjunction with the Superior and Inferior Recti. They are as follows:—4. *One* eye is made to revolve directly *inwards*, by the action of its Internal Rectus, whilst *the other* is turned *outwards* by the action of its External Rectus.—5. *One* eye is made to revolve *upwards* and *inwards*, by the conjoint action of the Superior and Internal Recti; *the other*, *upwards* and *outwards*, by the conjoint action of the Superior and External Recti.—6. *One* eye is made to revolve *downwards* and *inwards*, by the conjoint action of the Inferior and Internal Recti; *the other*, *downwards* and *outwards*, by the conjoint action of the Inferior and External Recti.—In these movements, *two different* muscles, the External and Internal Recti, are called into action on the two sides, with or without the superior and inferior Recti; but they are so employed for the purpose of directing the axes of the eyes towards *the same* point; and although, as just noticed, we can put the

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* Some persons can effect this voluntarily to a greater extent than others; but even then, they can only accomplish it by fixing the gaze upon some object situated between the eyes; and cannot call the adductor muscles into combined action in perfect darkness, or if the lids be closed. Even those who have the least power of effecting this extreme convergence by at once directing the eyes towards a very near object, can accomplish it by looking at an object placed at a moderate distance, and gradually bringing this nearer to the nose, keeping the eyes steadily fixed upon it. The unwonted character of the movement is shown in this,—that it can only be maintained, even for a short time, by a strong effort, producing a sense of fatigue.

two Internal Recti in action together, we cannot voluntarily cause the two External Recti to contract together, it not being possible that any object should be in such a position as to require this action for the direction of the axes of the eyes towards it.

674. The greater number of the foregoing movements may be performed unconsciously to ourselves, in obedience to a Voluntary determination to keep the direction of the eyes fixed, instead of to give motion to the eyeballs. Thus, if we gaze steadily at an object in front of us, and then depress the head forwards on its transverse axis, the eyeballs roll upwards upon their transverse axes (1) by the action of the Superior Recti, without our being aware of it; so if, whilst still maintaining the same fixed gaze, we raise the head into the vertical position and then depress it backwards, the eyeballs are rolled downwards (2) by the action of the Inferior Recti; if, under the same conditions, the head be made to rotate on its vertical axis from side to side, the eyeballs will be made to roll on their vertical axes in the contrary direction, by the External and Internal Recti (4) of the two sides respectively; so, by causing the head to move obliquely in the opposite directions, the reverse oblique movements (5 and 6) of the eyeballs are made to take-place by the continued fixation of the vision upon the same object. To these we have to add one more action, which cannot be called-forth in any other mode; namely, that rotation of the two eyes upon their antero-posterior axes, which takes-place probably by the instrumentality of the Oblique muscles, when we incline the head to one side or the other by rotating it upon its antero-posterior axis (§ 672). In all these movements, as in the preceding, the Will directs the *result;* and there is no other difference between them, than that which arises out of our consciousness of a change in the one case, and our unconsciousness in the other. It may here be remarked that Prof. Helmholtz* has recently adopted the same view as that just expressed in regard to the nature of the volitional direction and the influence of the guiding sensations; in corroboration of which he further mentions the important fact ascertained by Donders and himself, that by the use of a prism before one eye, *both* eyes may be made to move *outwards*, or one up and the other down,—still under the same fundamental law.—The truly Involuntary movements of the eyeballs, however, are performed under very different conditions; there being here no purposive direction or fixation of the gaze; and the muscular contractions not being determined by visual sensations, but being called-forth by nerve-force excited in some remote part. Of this we have an example in the normal revolution of both eyes upwards and inwards, which takes place in the acts of coughing, sneezing, winking, &c.; but far more remarkable illustrations are presented in those abnormal movements of the eyeballs, occurring in Convulsive diseases, in which there is neither harmony nor symmetry.

675. It has been stated to be a condition of single and distinct vision, that the *usual* axes of the eyes should be directed towards the object, in order that its picture should be thrown upon the parts of the two retinæ which are *accustomed* to act together (§ 611); but as this cannot take-place without the guidance of visual sensations, the movements of the eyeballs are wanting in harmony whenever the visual power has been deficient from birth. This is most remarkably the case, where the

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* In his Croonian Lecture, "Proceedings of the Royal Society," April 14, 1864, p. 193.

deficiency has been so complete that not even light can be distinguished; but the movements are frequently very far from being harmonious, in cases of congenital cataract, where a considerable amount of light is evidently admitted, but where no distinct image can be formed; and in such cases, the movements are most harmonious where the object is bright or luminous, and more vivid impressions are therefore made upon the retinæ. It is no objection to this doctrine to say, that persons who have *become* blind may still move their eyes in a harmonious manner; since, the habit of the association of particular movements having been once acquired, the guidance of the muscles may be effected by sensations derived from themselves, in the manner in which it takes-place in the laryngeal movements of the deaf and dumb (§ 525); and, as a matter of fact, a want of consent may often be observed where the blindness is total. The peculiar 'vacant' appearance, which may be noticed in the countenances of persons completely deprived of sight by amaurotic or other affections, which do not alter the external aspect of the eyes, seems to result from this,—that their axes are *parallel*, as if the individual were looking into distant space, instead of presenting that slight convergence which must always exist between them, when the eyes are fixed upon a definite object. This convergence, which is of course regulated by the Internal Recti, varies in degree according to the distance of the object; and it is astonishing how minute an alteration in the axes of the eyes becomes perceptible to a person observing them. For instance, A sees the eyes of B directed towards his face, but he perceives that B is *not looking* at him; he knows this by a sort of intuitive interpretation of the fact, that his face is not the point of convergence of B's eyes. But if B, who might have been previously looking at something nearer or more remote than A's face, fix his gaze upon the latter, so that the degree of the convergence of the axes is altered, without the general direction of the eyes being in the least affected, the change is at once perceived by the person so regarded; and the *eyes* of the two then *meet*. —It is an interesting confirmation of the principles here advocated, that when binocular vision cannot be obtained by directing the true axes of the eyes towards the object, as happens when an opaque spot exists upon the centre of the cornea, or an artificial pupil has been formed at the margin of the iris, there is an automatic tendency to the neutralization of the mischief, by such an action of the muscles as shall turn the *virtual* axis of the affected eye (that is, the axis in which the rays most directly enter the globe) towards the object, thus producing Strabismus, but *not* Double Vision.

676. The physiological principles which have now been stated, have an important application in the treatment of *Strabismus* by operation; a practice whose frequent want of success is due in great part to the injudicious selection of cases, and to the wrong measures pursued.—The degree in which habit accustoms parts of the retinæ that did not originally correspond, to work-together harmoniously, is remarkably shown by the fact, that patients who have been long affected with Convergent Strabismus, and who see equally well with both eyes (as many do), are not troubled with double vision. On the other hand, when a person whose eyes look straight before him, is the subject of a disorder which renders their motions in any degree irregular, he is at once affected with double vision. The same has been frequently noticed as an immediate

result of the successful operation for the cure of Strabismus, where vision is good in both eyes; for although the images were previously formed on parts of the retinæ which were very far from corresponding with each other, yet no sooner is the position of the eyes rectified (so that the relation between the situation of the images is the same as it would be in a sound eye), than the patient sees double. Now in these cases the difficulty very speedily diminishes, and the patient soon learns to see single. That there is a *greater* tendency to consent between the images, however, when they are formed upon the parts of the two retinæ which normally correspond, may be freely admitted: and this seems to be a principle of some importance in determining the re-adjustment of the eyes, after the operation for Strabismus. This re-adjustment is not always immediate; for after the muscle has been freely divided, the eye often remains somewhat inverted for a few days, gradually acquiring its straight position. The Author has known one case, in which, after such a degree of temporary inversion as seemed to render the success of the operation very doubtful, eversion actually took-place for a short time to a considerable extent; after which the axes became parallel, and have remained so ever since.—Another argument derivable from the results of this operation, in favour of the consensual movement being chiefly regulated by the correspondence in the seats of the impressions on the two retinæ, is, that it is much more successful in those cases in which the sight of the most displaced eye is good, than in those in which (as not unfrequently happens from long disuse) it is much impaired. In cases of the latter class, the cure is seldom complete.*

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* In reference to this subject, the Author would add that he is well convinced, from repeated observation, that those Surgeons are in the right, who have maintained that, in a large proportion of cases, Strabismus is caused by an affection of *both* sets of muscles or nerves, and not of one only; and that it then requires, for its perfect cure, the division of the corresponding muscles on both sides. Cases will be frequently met-with, in which this is evident; the two eyes being employed to nearly the same extent, and the patient giving to both a slight inward direction, when desired to look straight-forwards. In general, however, one eye usually looks straight-forwards, whilst the other is greatly inverted; and the sight of the inverted eye is frequently affected to a considerable degree by disuse; so that, when the patient voluntarily rotates it upon its proper axis, his vision with it is far from being distinct. Some Surgeons have maintained, that the inverted eye is usually the only one in fault, and consider that the division of the tendon of its Internal Rectus is sufficient for the cure. They would even divide its other tendons, if the parallelism be not restored, rather than touch the other eye. The Author is himself satisfied, however, that the restriction of the abnormal state to a single eye, is the exception, and not the rule, in all but very slight cases of Strabismus; and to this opinion he is led, both by the consideration of the mode in which strabismus first takes-place, and by the results of the operations which have come under his notice. If the eyes of an infant affected with cerebral disease be watched, there will frequently be observed in them very irregular movements; the axes of the two being sometimes extremely convergent, and then very divergent. This irregularity is rarely or never seen to be confined to one eye. Now, in a large proportion of cases of Strabismus, the malady is a consequence of some cerebral affection during infancy or childhood, which we can scarcely suppose to have affected one eye only. Again, in other instances we find the Strabismus to have resulted from the constant direction of the eyes to very near objects, as in short-sighted persons; and here, too, the cause manifestly affects both.—Now it is easy to understand why one eye of the patient should *appear* to be in its natural position, whilst the other is greatly inverted. The cause of Strabismus usually affects the two eyes somewhat unequally, so that one is much more inverted than the other. We will call the least inverted eye A, and the other B. In the ordinary acts of vision, the patient will make most use of the least inverted eye, A, because he can most readily look straight-forwards or outwards with it; but to bring it into the axis, or to rotate it outwards, necessitates a still more decided inversion of B. This remains the position of

3. *Energy and Rapidity of Muscular Contraction.*

677. The energy of Muscular contraction is of course to be most remarkably observed, in those instances in which the continual exercise of particular parts has occasioned an increased determination of blood towards them, and in consequence a permanent increase of their bulk (§ 316, III.). This has been the case, for example, with persons who have gained their livelihood by exhibiting feats of strength. Much will, of course, depend on the mechanically-advantageous application of muscular power; and in this manner effects may be produced, even by persons of ordinary strength, which would not have been thought credible. In lifting a heavy weight in each hand, for example, a person who keeps his back perfectly rigid, so as to throw the pressure vertically upon the pelvis, and only uses the powerful extensors of the thigh and calf, by straightening the knees (previously somewhat flexed), and bringing the leg to a right angle with the foot, will have a great advantage over one who uses his lumbar muscles for the purpose. A still greater advantage will be gained by throwing the weight more directly upon the loins, by means of a sort of girdle, shaped so as to rest upon the top of the sacrum and the ridges of the ilia; and by pressing with the hand upon a frame, so arranged as to bring the muscles of the arms to the assistance of those of the legs: in this manner, a single Man of ordinary strength may raise a weight of 2000 lbs.; whilst few who are unaccustomed to such exertions, can lift more than 300 lbs. in the ordinary mode. A man of great natural strength, however, has been known to lift 800 lbs. with his hands; and the same individual performed several other curious feats of strength, which seem deserving of being here noticed. "1. By the strength of his fingers, he rolled-up a very large and strong pewter dish. 2. He broke several short and strong pieces of tobacco-pipe with the force of his middle-finger, having laid them on the first and third finger. 3. Having thrust-in under his garter the bowl of a strong tobacco-pipe, his legs being bent, he broke it to pieces by the tendons of his hams, without altering the bending of the knee. 4. He broke such another bowl between his first and second fingers, by pressing them together sideways. 5. He lifted a table six feet long, which had half a hundred-weight hanging at the end of it, with his teeth, and held it in that position for a considerable time. It is true, the feet of the table rested against his

things,—the patient usually looking straight-forwards with A, which is the eye constantly employed for the purposes of vision,—and frequently almost burying the other eye, B, the vision in which is of very little use to him, under the inner canthus. When, therefore, the tendon of the internal rectus of B is divided, the relative position of the two is not entirely rectified. Sometimes it appears to be so for a time; but the strabismus then begins to return, and it can only be checked by division of the tendon of the other eye, A; after which, the cure is generally complete and permanent. That it has not been so in many of the patients on whom operations have been performed, the Author attributes, without the slightest doubt in his own mind, to the neglect of the second operation. As just now stated, the sight of the most inverted eye is frequently very imperfect; indeed it is sometimes impaired to such an extent, that the patients speak of it as entirely useless. That this impairment results in part from disuse merely, seems very evident, from the great improvement which often succeeds the rectification of the axes.—A valuable memoir by Prof. Pancoast, on the 'Operation for Strabismus,' founded on the results of about 1000 cases, will be found in the "Philadelphia Medical Examiner," vol. vii., and an abstract of it in the "Brit. and For. Med.-Chir. Review," July, 1852, p. 262.

knees; but as the length of the table was much greater than its height, that performance required a great strength to be exerted by the muscles of his loins, neck, and jaws. 6. He took an iron kitchen poker, about a yard long, and three inches in circumference, and holding it in his right hand, he struck it on his bare left arm between the elbow and the wrist, till he bent the poker nearly to a right angle. 7. He took such another poker, and, holding the ends of it in his hands, and the middle of it against the back of his neck, he brought both ends of it together before him; and, what was yet more difficult, he pulled it straight again."* Haller mentions an instance of a man, who could raise a weight of 300 lbs., by the action of the elevator muscles of his jaw: and that of a slender girl, affected with tetanic spasm, in whom the extensor muscles of the back, in the state of tonic contraction or opisthotonos, resisted a weight of 800 lbs. laid on the abdomen with the absurd intention of straightening the body. In a recent paper by Professor Haughton,† the conclusion is arrived at, that 1 lb. weight of human muscle is capable of lifting 1·56 ton through 1 foot before it is exhausted; whilst Mr. H. F. Baxter‡ found from his experiments that 1 grain of frog's muscle is on the average capable of raising a weight of 608 grains through a space of 1-53rd of an inch, though considerable differences exist in regard to sex (1 grain of the muscle of male frogs raising 656 grains, and 1 grain of the muscle of female frogs raising 579 grains), age, and general condition of the animal. His experiments also show the interesting circumstance that whilst there is a loss of weight in the animal during muscular contraction, there is an increase of weight in the individual muscles experimented-on. —It is to be recollected, that the mechanical application of the power developed by muscular contraction to the movement of the body, is very commonly disadvantageous as regards *force*; being designed to cause the part moved to pass over a much greater *space* than that through which the muscle contracts. Thus the Temporal muscle is attached to the lower jaw, at about one-third of the distance between the condyle and the incisors; so that a shortening of the muscle to the amount of half an inch, will draw-up the front of the jaw through an inch and a half; but a power of 900 lbs. applied by the muscle, would be required to raise 300 lbs. bearing on the incisors. In the case of the fore-arm and leg, the disproportion is much greater; the points of attachment of the muscles by which the knee and elbow-joints are flexed and extended, being much closer to the fulcrum, in comparison with the distance of the points on which the resistance bears.—The mechanical power exerted by muscle in contraction may be calculated as in any mechanical machine by multiplying the weight lifted by the height to which it is raised. Weber obtained the following values for the muscle of a frog:—

	Weight lifted in Grammes.		Height in Mm.		Mechanical effect in Grammillimetres
a	5	× by	27·6	=	138
b	15		25·1		376
c	25		11·45		286
d	35		6·3		220

That is to say, that 138 grammillimetres are equal to 5 grammes raised

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* Desaguliers' "Philosophy," vol. ii.

† "Outlines of a New Theory of Muscular Action," Dublin, 1863.

‡ 'On Muscular Power,' in the "Edin. New Phil. Journ.," vol. xviii. p. 194.

27·6 mm. or to 27·6 grammes raised 5 mm. It will be seen from the table that the mechanical effect increases to a certain point with the weighting, and then gradually diminishes: it was found that different muscles had their maximum at different weightings.—The power of the muscles appears to vary in different animals, being greatest in proportion to their size in Insects.

678. The rapidity of the changes of position of the component particles of muscular fibres, may, as Dr. Alison justly remarks,* be estimated, though it can hardly be conceived, from various well-known facts. The pulsations of the heart can sometimes be distinctly numbered in children, at more than 200 in the minute; and as each contraction of the ventricles occupies only half the time of the whole pulsation, it must be accomplished in 1-400th of a minute, or 3-20ths of a second. Again, it is certain that, by the movements of the tongue and other organs of speech, 1500 letters can be distinctly pronounced by some persons in a minute: every one of these must require a separate contraction of muscular fibres; and the production and cessation of each of the sounds, implies that each separate contraction must be followed by a relaxation of equal length; each contraction, therefore, must have been effected in 1-3000th part of a minute, or in 1-50th of a second. Haller calculated that, in the limbs of a dog at full speed, muscular contractions must take place in less than 1-200th of a second, for many minutes at least in succession.—All these instances, however, are thrown into the shade, by those which may be drawn from the class of Insects. The rapidity of the vibrations of the wings may be estimated from the musical tone which they produce; it being easily ascertained by experiments, what number of vibrations are required to produce any note in the scale (§ 628). From these data, it appears to be the necessary result, that the wings of many Insects strike the air *many hundred* or even *many thousand* times in every *second*.—The minute precision with which the degree of muscular contraction can be adapted to the designed effect, is in no instance more remarkable than in the Glottis. The musical pitch of the tones produced by it, is regulated by the degree of tension of the *chordæ vocales*, which are possessed of a very considerable degree of elasticity (§ 681). According to the observations of Muller,† the average length of these, in the male, in a state of repose, is about 73-100ths of an inch; whilst, in the state of greatest tension it is about 93-100ths; the difference being therefore 20-100ths, or *one-fifth* of an inch: in the female glottis, the average dimensions are about 51-100ths and 63-100ths respectively; the difference being thus about *one-eighth* of an inch. Now the natural compass of the voice, in most persons who have cultivated the vocal organ, may be stated at about two octaves, or 24 semitones. Within each semitone, a singer of ordinary capability could produce at least ten distinct intervals; so that of the total number, 240 is a very moderate estimate. There must, therefore, be at least 240 different states of tension of the Vocal Cords, every one of which is producible by the will, without any previous trial; and the *whole* variation in the length of the cords being not more than one-fifth of an inch, even in man, the variation required to pass from one interval to another, will not be more than

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* "Cyclopædia of Anatomy and Physiology," Art. 'Contractility.'

† "Elements of Physiology," Baly's translation, p. 1018.

1-1200th of an inch. And yet this estimate is much below that which might be truly made from the performances of a practised vocalist.[*]

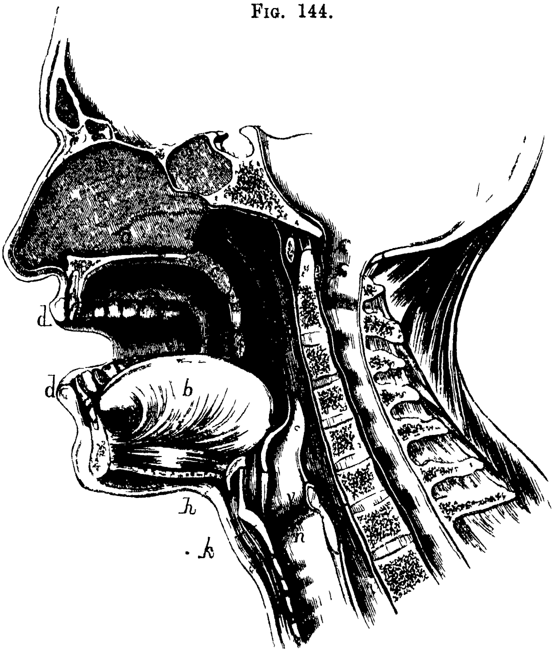
CHAPTER XIV.

OF THE VOICE AND SPEECH.

1. *Of the Larynx, and its Actions.*

679. THE sounds produced by the organ of Voice constitute the most important means of communication between Man and his fellows; and the power of Speech has, therefore, a primary influence, as well on his

FIG. 144.

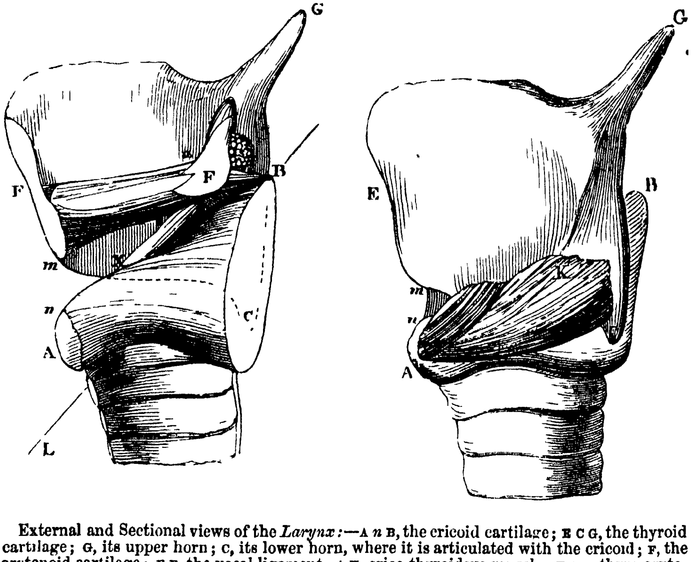


Median Section of *Mouth, Nose, Pharynx,* and *Larynx.*—*a,* septum of nose; below it, section of hard palate, *b,* tongue, *c,* section of velum pendulum palati, *d, d,* lips; *u,* uvula; *r,* anterior arch or pillar of fauces; *i,* posterior arch, *t,* tonsil, *p,* pharynx; *h,* hyoid bone; *k,* thyroid cartilage, *n,* cricoid cartilage, *s,* epiglottis; *v,* glottis; 1, posterior opening of nares; 3, isthmus faucium, 4, superior opening of larynx, 5, passage into œsophagus; 6, mouth of right Eustachian tube

[*] It is said that the celebrated Madame Mara was able to sound 100 different intervals between each tone. The compass of her voice being at least three octaves, or 21 tones, the total number of intervals was 2100, all comprised within an extreme variation of one-eighth of an inch; so that it might be said that she was able to determine the contractions of her vocal muscles to nearly the *seventeen-thousandth* of an inch.

physical condition, as on the development of his mental faculties. It is necessary to bear in mind that Vocal sounds, and Speech or articulate Language, are two things entirely different; and that the former may be produced in great perfection, where there is no capability for the latter. Hence we might at once infer, that the instrument for the production of vocal sounds is distinct from that by which these sounds are modified into articulate speech; and this we easily discover to be the case, the voice being unquestionably produced in the *larynx*, whilst the modifications of it by which language is formed, are effected for the most part in the *oral cavity*.—The structure and functions of the former, then, first claim our attention.

Fig. 145. Fig. 146.

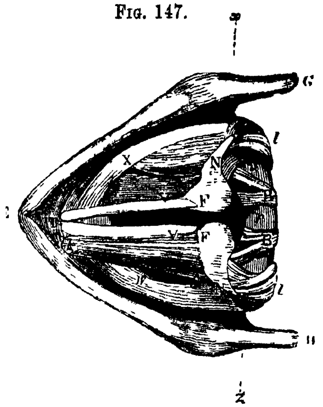


External and Sectional views of the *Larynx*:—A *n* B, the cricoid cartilage; E C G, the thyroid cartilage; G, its upper horn; C, its lower horn, where it is articulated with the cricoid; F, the arytenoid cartilage; E F, the vocal ligament; A K, crico-thyroideus muscle; F *e m*, thyro-arytenoideus muscle; X *e*, crico-arytenoideus lateralis; *s*, transverse section of arytenoideus transversus; *m n*, space between thyroid and cricoid; B L, projection of axis of articulation of arytenoid with thyroid.

680. It will be remembered that the Trachea is surmounted by a stout cartilaginous annulus, termed the *Cricoid* cartilage (Figs. 145, 146, A B, Fig. 147, *r u* x *w*); which serves as a foundation for the superjacent mechanism. This is embraced (as it were) by the *Thyroid* (Figs. 145, 146, E C G, Fig. 147, G E H), which is articulated to its sides by the lower horns (Figs. 145, 146, C), round the extremities of which it may be considered to turn as on a pivot. In this manner, the lower front border of the Thyroid cartilage, which is ordinarily separated by a small interval (Figs. 145, 146, *m n*) from the upper margin of the Cricoid, may be made to approach it or to recede from it; as any one may easily ascertain, by placing his finger against the little depression which may be readily felt externally, and observing its changes of size, whilst a range of different tones is sounded; for it will then be noticed that, the higher the note,

the more the two cartilages are made to approximate, whilst they separate in proportion to the depth of the tones.* Upon the upper surface of the back of the Cricoid, are seated the two small *Arytenoid* cartilages (Figs. 145, 147, F F); these are fixed in one direction by a bundle of strong ligaments, which tie them to the back of the cricoid; but they have some power of moving in other directions, upon a kind of articulating surface. The direction of the surface, and the mode in which these cartilages are otherwise attached, cause their movement to be a sort of rotation in a plane which is nearly horizontal but partly downwards; so that their vertical planes may be made to separate from each other, and at the same time to assume a slanting position. This change of place will be better understood, when the action of the muscles is described. To the summit of the Arytenoid cartilages are attached the *chordæ vocales* or Vocal Ligaments (Fig. 145, E F, Fig. 147, T V), which stretch-across to the front of the Thyroid cartilage; and it is upon the condition and relative situation of these ligaments, that their action depends. It is evident that they may be rendered more or less tense, by the movement of the Thyroid cartilage just described; being tightened by the depression of its front upon the Cricoid cartilage, and slackened by its elevation. On the other hand, they may be brought into more or less close apposition, by the movement of the Arytenoid cartilages; being made to approximate nearly, or to recede in such a manner as to cause the rima glottidis to assume the form of a narrow V, by the revolution of these cartilages.—We shall now inquire into the actions of the muscles upon the several parts of this apparatus; and first into those of the larynx alone.

FIG. 147.



Bird's-eye view of *Larynx* from above:—G E H, the thyroid cartilage, embracing the ring of the cricoid, *r u* X *w*, and turning upon the axis, *x z*, which passes through the lower horns, C, Fig. 145; N F, N F, the arytenoid cartilages, connected by the arytenoideus transversus; T V, T V, the vocal ligaments; N X, the right crico-arytenoideus lateralis (the left being removed); V *k f*, the left thyro-arytenoideus (the right being removed); N *l*, N *l*, the crico-arytenoidei postici; B, B, the crico-arytenoid ligaments.

681. The depression of the front of the Thyroid cartilage, and the consequent *tension* of the Vocal Ligaments, is occasioned by the conjoint action of the *Crico-thyroidei* (Fig. 146, A K) on both sides; and the chief antagonists to these are the *Thyro-arytenoidei* (Fig. 145, F *m*, Fig. 147, V *k f*), which draw the front of the thyroid back towards the arytenoid cartilages, and thus *relax* the vocal ligaments. These two pairs of muscles may be regarded as the principal governors of the *pitch* of the notes, which, as we shall hereafter see, is almost entirely regulated by the tension of the ligaments; their action is assisted, however, by that of other muscles presently to be mentioned.†—The arytenoid cartilages are made

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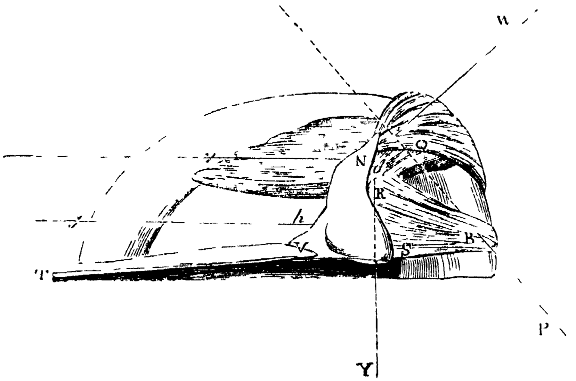
* In making this observation, it is necessary to put out of view the general movement of the Larynx itself, which the finger must be made to follow up and down.

† Dr. P. Martyn has adduced various observations to show that the Thyroid body

to diverge from each other, by means of the *Crico-arytenoidei postici* (Fig. 147, N *l*) of the two sides, which proceed from their outer corners, and turn somewhat round the edge of the Cricoid, to be attached to the lower part of its back; their action is to draw the outer corners backwards and downwards, so that the points to which the vocal ligaments are attached are separated from one another, and the rima glottidis is thrown *open*. This will be at once seen from the preceding diagram, in which the direction of traction of the several muscles is laid-down.—The action of these muscles is partly antagonised by that of the *Crico-arytenoidei laterales* (Fig. 147, N X), which run forwards and downwards from the outer corners of the Arytenoid cartilages, and whose contraction tends to bring their anterior points into the same straight line, depressing them at the same time, so as thus to *close* the glottis. These muscles are assisted by the *Arytenoideus transversus* (Fig. 147), which connects the posterior faces of the Arytenoid cartilages, and which, by its contraction, draws them together. By the conjoint action, therefore, of the Crico-arytenoidei laterales and of the Arytenoideus transversus, the whole of the adjacent faces of the Arytenoid cartilages will be approximated, and the points to which the vocal ligaments are attached will be depressed.—But if the Arytenoideus be put in action in conjunction with the Crico-arytenoidei postici, the tendency of the latter to separate the Arytenoid cartilages being antagonised by the former, its backward action only will

FIG. 148.



Part of Fig. 147 enlarged, to show the *Direction of th[illegible]uscular Forces* which act on the Arytenoid cartilage:—N V S, the right Arytenoid cartilage; T V, its vocal ligament; B R S, bundle of ligaments uniting it to Cricoid; O P, projection of its axis of articulation; *h g*, direction of the action of the Thyro-arytenoideus; N X, direction of Crico-arytenoideus lateralis; N W, direction of Crico-arytenoideus posticus; N Y, direction of Arytenoideus transversus.

exerts an important influence on the pitch of the notes, by giving a certain firmness, rigidity, and tension to the larynx. He also suggests that this body may act as a *loader*, rendering the vibrations of the vocal cords slower and longer, and the tone in consequence fuller, louder, and deeper, thus compensating for the small size of the larynx; finally he believes that it aids, by its changes in shape, bulk, and density, in producing the wonderful qualities of modulation and expression peculiar to the human voice. See "Proceedings of the Royal Society," vol. viii. p. 315.

be exerted; and thus it may be caused to aid the Crico-thyroidei in rendering tense the vocal ligaments. This action will be further assisted by the *Sterno-thyroidei*, which tend to depress the Thyroid cartilage by pulling from a fixed point below;* and the *Thyro-hyoidei* will be the antagonists of these, when they act from a fixed point above, the Os Hyoides being secured by the opposing contraction of several other muscles.—The respective actions of these muscles will be best comprehended by the following Table.

Govern the pitch of the Notes.

Antagonists.	CRICO-THYROIDEI STERNO-THYROIDEI	Depress the front of the Thyroid cartilage on the Cricoid, and *stretch* the vocal ligaments; assisted by the Arytenoideus and Crico-arytenoidei postici.
	THYRO-ARYTENOIDEI THYRO-HYOIDEI	Elevate the front of the Thyroid cartilage, and draw it towards the Arytenoids, *relaxing* the vocal ligaments.

Govern the Aperture of the Glottis.

ntagonists.	CRICO-ARYTENOIDEI POSTICI ..	*Open* the Glottis.
	CRICO-ARYTENOIDEI LATERALES ARYTENOIDEUS TRANSVERSUS ...	Press together the inner edges of the Arytenoid cartilages, and *close* the Glottis.

682. The muscles which stretch or relax the Vocal ligaments, are entirely concerned in the production of Voice: those which govern the aperture of the Glottis have important functions in connection with the Respiratory actions in general, and stand as guards (so to speak) at the entrance to the lungs. These separate actions are easily made evident. In the ordinary condition of rest, it seems probable that the Arytenoid cartilages are considerably separated from each other; so as to cause a wide opening to intervene between their inner faces and between the vocal ligaments, through which the air freely passes; and the vocal ligaments are at the same time in a state of complete relaxation.—We can close the aperture of the Glottis by an exertion of the will, during either inspiration or expiration; and its closure by an automatic impulse forms part of the acts of Coughing and Sneezing (§ 280), besides giving-rise to those more prolonged impediments to the ingress and egress of air, which have been already noticed as resulting from disordered states of the Nervous system. With these actions, the muscles which regulate the tension of the vocal ligaments have nothing to do; and we have seen that they are performed by the instrumentality of the Pneumogastric or proper Respiratory nerve (§§ 277, 278).—The appearances which present themselves when the interior of the Larynx is examined during life are, according to Prof. Czermak, that in the almost semilunar space bounded by the posterior wall of the Pharynx (Fig. 149) and the base of the tongue, the upper curved free edge of the epiglottis (*e*) is seen, its lateral portions just touching the posterior pharyngeal wall, and

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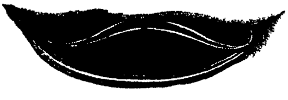
* These are not usually reckoned among the principal muscles concerned in regulating the voice; but that they are so, any one may convince himself by placing his finger just above the sternum, whilst he is sounding high notes; a strong feeling of muscular tension is then at once perceived.

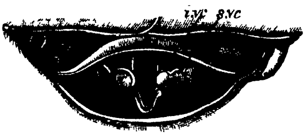
its central portion arching forwards, so as to leave an interval for the passage of air in the median line. Near the centre of the cleft between the upper border of the epiglottis and the walls of the pharynx, a transverse band or cushion (*c*) is also seen, of a reddish colour, and formed by the edge of the fold of mucous membrane sustained between the two separated arytenoid cartilages (*a*, *a*). The anterior outline of the fold is concave in front, and forms with the superior border of the epiglottis, which is concave behind and situated a little higher, a narrow transversely-elliptical fissure. If the vowel *a* be now sounded as in *ah* or *eh*, the semilunar space behind the base of the tongue is enlarged, the epiglottis rises and separates from the posterior wall of the pharynx, the glottis becomes widely opened, and a considerable portion of the anterior wall of the trachea can be perceived. A small rounded swelling situated to the outer side of the tubercles of Santorini, which was previously concealed by the lateral border of the epiglottis, now also comes into view. The movements of the arytenoid cartilages during the production of vocal sounds can be very distinctly observed by the laryngoscope, and the account given by Prof. Czermak possesses considerable interest, since it fully corroborates the views derived from theory and experiment on the dead subject, which had been expressed before the introduction of the instrument. As soon as we wish to utter a sound, the two arytenoid cartilages raise themselves in the fold of mucous membrane which covers them, and approach one another with surprising mobility. This movement effects the approximation of the vocal cords, and consequently the constriction of the Glottis (Fig. 150). The study of the mode of formation of the gravest chest-sounds is extremely difficult, on account of the arytenoid cartilages becoming elevated and rapidly approaching one another until they come almost into complete contact, whilst they bend under the border of the depressed epiglottis in such a manner that the latter, as viewed by the laryngoscope, entirely conceals the interior of the Larynx. During the emission of the most acute sounds, the Glottis is contracted in a linear form (Fig. 151); on each side we perceive the vocal cords distinguished by their whitish-yellow colour, and a little to the outer row groove indicating the position of the ventricles of Morgagni. Further outwards again are the false or superior vocal cords. These par

FIG. 149.



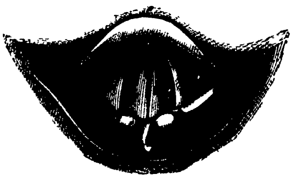
Condition of the *Larynx* as seen by the Laryngoscope during tranquil respiration:—*e*, epiglottis; *œ*, fissure-like opening of œsophagus; *c*, fold of mucous membrane bounding the opening of the glottis posteriorly, and extending between the tubercles of the cartilages of Santorini.

FIG. 150.



Condition of the *Larynx* during the emission of the broad vowel sound (A):—*a*, cartilages of Santorini surmounting the arytenoid cartilages; *e*, epiglottis; *i v c*, inferior or true vocal cord; *s v c*, superior or false vocal cord of right side.

FIG. 151.



Condition of the *Larynx* during the emission of high or acute sound:—*e*, epiglottis; *cu*, cushion of epiglottis; *i v c*, true vocal cord; *s v c*, false vocal cord.

with the erected arytenoid cartilages, the epiglottis pulled upwards and forwards, and the aryteno-epiglottidian ligaments, together form a short and stiff tube situated above the Glottis; the whole appearing, from the sensations we experience during the experiment, to be in a state of very great tension.* That the aperture of the glottis is greatly narrowed during the production of sounds, is easily made evident to one's-self, by comparing the time occupied by an ordinary expiration, with that required for the passage of the same quantity of air during the sustenance of a vocal tone. Further, the size of the aperture is made to vary in accordance with the note which is being produced; of this, too, any one may convince himself, by comparing the times during which he can hold out a low and a high note; from which it will appear that the aperture of the glottis is so much narrowed in producing a high note, as to permit a far less rapid passage of air than is allowed when a low one is sounded. According to Kempelen no sound is elicited when the distance between the Chordæ Vocales exceeds 1-10th to 1-12th of an inch. The muscular movements concerned in the act of vocalization, appear to be called-forth by the instrumentality of the motor fibres, partly derived from the Spinal Accessory nerve, which are contained in the Pneumogastric (§ 481).

683. We have now to inquire what is the operation of the Vocal Ligaments in the production of sounds; and in order to comprehend this, it is necessary to advert to the conditions under which tones are produced by instruments of various descriptions having some analogy with the Larynx. These are chiefly of three kinds; strings, flute-pipes, and reeds or tongues.—The Vocal Ligaments were long ago compared by Ferrein to vibrating *strings*; and at first sight there might seem a considerable analogy, the sounds which both produce being elevated by increased tension. This resemblance disappears, however, on more accurate comparison; for it may be easily ascertained by experiment, that no string so short as the vocal ligaments could give a clear tone at all to be compared in depth with that of the lowest notes of the human voice; and also, that the scale of changes produced by increased tension is fundamentally different. When strings of the same length but of different tensions are made the subject of comparison, it is found that the number of vibrations is in proportion to the square-roots of the extending forces. Thus, if a string extended by a given weight produce a certain note, a string extended by four times that weight will give a note in which the vibrations are twice as rapid; and this will be the octave of the other. If nine times the original weight be employed, the vibrations will be three times as rapid as those of the fundamental note, producing the twelfth above it. Now by fixing the larynx in such a manner that the vocal ligaments can be extended by a known weight, Müller has ascertained that the sounds produced by a variation of the extending force do not follow the same ratio; and therefore the condition of these ligaments cannot be simply that of vibrating cords. Further, although a cord of a certain length, which is adapted to give-out a clear and distinct note equal in depth to the lowest of the human voice, may be made by increased tension to produce all the superior notes (which, in stringed instruments, are ordinarily obtained by shortening the strings), it does

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* "On the Laryngoscope," Syd. Soc. Trans., 1861, pp. 37-8; see also "The Laryngoscope," by George D. Gibb, M.D., London, 1863.

not follow that a short string, which, with moderate tension, naturally produces a high note, should be able, by a diminution of the tension, to give-out a deep one; for, although this might be theoretically possible, yet it cannot be accomplished in practice; since the vibrations become irregular on account of the diminished elasticity.* These considerations are in themselves sufficient to destroy the supposed analogy; and to prove that the Chordæ Vocales cannot be reduced to the same category with vibrating strings.

684. The next kind of instrument with which some analogy might be suspected, is the *flute-pipe*, in which the sound is produced by the vibration of an elastic column of air contained in the tube; and the pitch of the note is determined almost entirely by the length of the column, although slightly modified by its diameter, and by the nature of the embouchure or mouth from which it issues. This is exemplified in the German Flute, and in the English Flute or Flageolet; in both of which instruments the acting length of the pipe is determined by the interval between the embouchure and the nearest of the side-apertures; by opening or closing which, therefore, a modification of the tone is produced. In the Organ, of which the greater number of pipes are constructed upon this plan, there is a distinct pipe for every note; and their length increases in a regular scale. It is, in fact, with flute-pipes as with strings,—that a diminution in length causes an increase in the number of vibrations, in a simply-inverse proportion; so that of two pipes, one being half the length of the other, the shorter will give a tone which is the octave above the other, the vibrations of its column of air being twice as rapid. Now there is nothing in the form or dimensions of the column of air between the larynx and the mouth, which can be conceived to render it at all capable of such vibrations as are required to produce the tones of the Human voice; though there is some doubt whether it be not the agent in the musical tones of certain Birds. The length that would be required in an open pipe to give the lowest G of the ordinary bass voice, is nearly six feet; and the conditions necessary to produce the higher notes from it, are by no means those which we find to exist in the process of modulating the human voice.

685. We now come to the third class of instruments, in which sound is produced by the vibration of *reeds* or *tongues;* these may either possess elasticity in themselves, or be made elastic by tension. The 'free' reeds of the Accordion, Concertina, Seraphine, Harmonium, &c., are examples of instruments of this character, in which the lamina vibrates in a sort of frame that allows the air to pass-out on all sides of it through a narrow channel, thus increasing the strength of the blast: whilst in the Hautboy, Bassoon, &c., and in the Organ-pipes of similar construction, the reed covers an aperture at the side of one end of a pipe. In the former kind, the sound is produced by the vibration of the tongue alone, and is regulated entirely by its length and elasticity; whilst in the latter its pitch is dependent upon this conjointly with the length of the tube, the column of air contained in which is thrown into simultaneous vibration. Some interesting researches on the effect produced on the pitch of a sound

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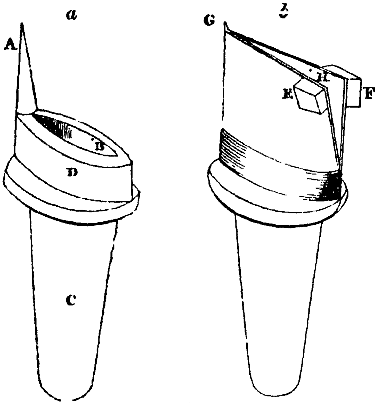
* Thus it would be impossible to produce good Bass notes on the strings of a Violin, by diminishing their tension; the length afforded by the Violoncello or Double Bass is requisite.

given by a reed through the union of it with a tube, have been made by M. W. Weber; and, as they are important in furnishing data by which the real nature of the vocal organ may be determined, their chief results will be here given.—I. The pitch of a reed may be lowered, but cannot be raised, by joining it to a tube. II. The sinking of the pitch of the reed thus produced is at the utmost not more than an octave. III. The fundamental note of the reed thus lowered may be raised again to its original pitch by a further lengthening of the tube, whilst by a further increase it is again lowered. IV. The length of tube necessary to lower the pitch of the instrument to any given point, depends on the relation which exists between the frequency of the vibrations of the tongue of the reed, and those of the column of air in the tube, each taken separately.—From these data, and from those of the preceding paragraph, it follows that, if a wind-instrument can, by the prolongation of its tube, be made to yield tones of any depth in proportion to the length of the tube, it must be regarded as a flute-pipe; whilst if its pitch can only be lowered an octave or less (the embouchure remaining the same) by lengthening the tube, we may be certain that it is a reed instrument. The latter proves to be the case in regard to the Larynx.

686. It is evident from the foregoing considerations, that the action of the Larynx has more analogy to that of *reed* instruments, than it has to that either of vibrating *strings*, or of *flute-pipes;* and though there would seem, at first sight, to be a marked difference in character between the vocal ligaments and the tongue of any reed instrument, this difference is really by no means considerable. In a reed, elasticity is a property of the tongue itself, when fixed at one end, the other vibrating freely; but by a membranous lamina, fixed in the same manner, no tone would be produced. If such a lamina, however, be made elastic by a moderate degree of tension, and be fixed in such a manner as to be advantageously acted-on by a current of air, it will give a distinct tone. It is observed by Muller, that membranous tongues made elastic by tension may have either of three different forms:—I. That of a band extended by a cord, and included between two firm plates, so that there is a cleft for the passage of air on each side of the tongue. II. The elastic membrane may be stretched over the half or any portion of the end of a short tube, the other part being occupied by a solid plate, between which and the elastic membrane a narrow fissure is left. III. Two elastic membranes may be extended across the mouth of a short tube, each covering a portion of the opening, and having a chink left open between them.—This last is evidently the form most allied to the Human Glottis; but it may be made to approximate still more closely, by prolonging the membranes in a direction parallel to that of the current of air, so that not merely their edges, but their whole planes, shall be thrown into vibration. Upon this principle, a kind of *artificial glottis* has been constructed by Mr. Willis; the conditions of action and the effects of which are so nearly allied to that of the real instrument, that the similar character of the two can scarcely be doubted. The following is his description of it. "Let a wooden pipe be prepared of the form of Fig. 152 *a*, having a foot, C, like that of an organ-pipe, and an upper opening, long and narrow, as at B, with a point, A, rising at one end of it. If a piece of leather, or still better, of sheet India-rubber, be doubled round this point, and secured

by being bound round the pipe at D with strong thread, as in Fig. 152 *b*, it will give us an artificial glottis with its upper edges G H, which may be made to vibrate or not, at pleasure, by inclining the planes of the edges. A couple of pieces of cork, E F, may be glued to the corners, to make them more manageable. From this machine various notes may be obtained, by stretching the edges in the direction of their length G H; the notes rising in pitch with the increased tension, although the length of the vibrating edge is increased. It is true that a scale of notes equal in extent to that of the human voice cannot be obtained from edges of leather; but this scale is much greater in India-rubber than in leather, and the elasticity of them both is so much inferior to that of the vocal ligaments, that we may readily infer that the greater scale of the latter is due to its greater elastic powers." By other experimenters, the tissue forming the middle coat of the arteries has been used for this purpose, in the moist state, with great success; with this, the tissue of the vocal ligament is nearly identical. It is worthy of remark that, in all such experiments, it is found that the two membranes may be thrown into vibration, when inclined *towards* each other in various degrees, or even when they are in parallel planes, and their edges only approximate; but that the least inclination *from* each other (which is the position the vocal ligaments have during the ordinary state of the glottis, § 682), completely prevents any sonorous vibrations from being produced.

FIG. 152.



Artificial Glottis.

687. The pitch of the notes produced by membranous tongues may be affected in several ways. Thus, an increase in the strength of the blast, which has little influence on metallic reeds, raises *their* pitch very considerably; and in this manner the note of a membranous reed may be raised by semitones, to as much as a fifth above the fundamental. The addition of a pipe has nearly the same effect on their pitch, as on that of metallic reeds; but it cannot easily be determined with the same precision. Several different notes may be produced with a pipe of the same length; but there is a certain length of the column of air, which is the one best adapted for each tone. It has been recently ascertained, moreover, that the length of the pipe prefixed to the reed has a considerable influence on its tone, rendering it deeper in proportion as it is prolonged, down to nearly the octave of the fundamental note; but the pitch then suddenly rises again, as in the case of the tube placed beyond the reed. The researches of Müller, however, have not succeeded in establishing any very definite relation between the lengths of the two tubes, in regard to their influence on the pitch of the reed placed between them.

688. From the foregoing statements it appears, that the true theory of

the Voice may now be considered as well established, in regard to this essential particular,—that the sound is the result of the vibrations of the vocal ligaments, which take place according to the same laws with those of metallic or other elastic tongues: and that the pitch of the notes is chiefly governed by the tension of these laminæ.* With respect, however, to the mode and degree in which these tones are modified by the shape of the air-passages both above and below the larynx, by the force of the blast and by other concurrent circumstances, little is certainly known ; but no doubt can be felt that these modifications are of great importance, when we observe the great amount of muscular action which takes place consentaneously with the production of vocal tones, and which seems designed to alter the length and tension of the various parts of the *vocal tube*, so that they may vibrate synchronously with the *vocal cords*. Thus, during the ascent of the voice from the deeper to the higher notes of the scale, we find the whole larynx undergoing an elevation towards the base of the cranium, the thyroid cartilage being drawn up within the os-hyoides, so as even to press on the epiglottis; at the same time, the small space between the thyroid and cricoid cartilages, or crico-thyroid chink, is closed by the depression of the front of the former upon the latter (§ 680); the velum palati is depressed and curved forwards; and the tonsils approach one another. The reverse of all these movements takes place during the descent of the voice.—A very important adjunct to the production of the higher notes has been pointed-out by Muller, as being afforded by the modification in the space included between the two sides of the thyroid cartilage, which is effected by the thyro-arytenoidei. He had experimentally ascertained that the introduction of a hollow plug into the upper end of the pipe beneath his artificial larynx (and therefore just below the reed), by diminishing its aperture, produced a considerable elevation of the tone. The action may be imitated in the human larynx, when made the subject of experiment, by compressing the thyroid cartilage laterally; and in this manner, the natural voice can be made to extend through a range that could otherwise be only reached by a falsetto. The influence of the prefixed and superadded tubes, in modifying the tones produced by the Human larynx, has been found by Prof. Muller not to be at all comparable to that which they exercised over the artificial larynx; the reason of which difference does not seem very apparent. It appears, however, that there is a certain length of the prefixed tube—as there is a certain distance of the vibrating laminæ, and a certain length or form of the tube above,—which is most favourable to the production of each note; and the downward movement of the whole vocal organ, which takes-place when we are sounding deep notes, and its rise during the elevation of the tones, have been supposed to answer the purpose of making this adjustment in the length of the trachea; but this requires the supposition that the real length of the trachea is shortened whilst it appears extended,—for which there seems no foundation. It is considered by Mr. Wheatstone, that the column of air in the trachea may divide itself into 'harmonic lengths,' and may produce a *reciprocation* of the tone given by the vocal ligaments (§ 631); and in this manner he considers that the falsetto notes are to be explained. It may be added that the partial closing of the epiglottis seems to assist in the production of deep notes, just as the partial covering of the top of a short pipe fixed to a reed will lower its tone; and that something of this kind takes place during natural vocalisation, would appear from the retraction and depression of the tongue, which accompany the lowering of the front of the head when the very lowest notes are being sounded. The experiments of Savart have shown, that a cavity which only responds to a shrill note, when its walls are firm and dry, may be made to afford a great variety of lower tones, when its walls are moistened and relaxed in various degrees. This observation may probably be applied also to the trachea.

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* It is considered, however, by Mr. Bishop ("Cyclop. of Anat. and Physiol," vol. iv. p. 1486), that the vocal apparatus combines the properties of a stretched cord, a membranous pipe with a column of air vibrating in it, and a reed ; and is the perfect type, of which these instruments are only imperfect adaptations. The Author is unable, however, to deduce from Mr. Bishop's previous statements the grounds upon which he makes this assertion ; and does not understand how any instrument *can* combine the actions of *strings* and of *tongues*, the laws of whose vibration are so different. That the column of air in the air-passages is thrown into vibration consentaneously with the production of sound by the vocal cords, and intensifies that sound by reciprocation, can scarcely be doubted ; but the reasons previously given appear to the Author sufficient to disprove the notion that this vibration is at all more essential to the production of the vocal tone, than it is in the reed-pipe of an organ.

689. The *falsetto* is a peculiar modification of the voice, differing from the 'chest-voice,' not merely in the higher pitch of its notes, but also in their quality; its tones being less reedy, and more like the 'harmonic notes' of stringed and wind instruments. In some individuals, the chest-voice passes by imperceptible gradations into the falsetto, whilst in others the transition is abrupt; and some persons can sound the same notes in the two different registers, these notes forming the upper part of the scale of the chest-voice, and the lower part of the falsetto.*—With regard to the theory of the production of the falsetto voice, there has been considerable difference of opinion amongst Physiologists; and it cannot be regarded as fully determined. By Magendie and Mayo it was maintained that these tones are produced by the vibration of the vocal cords along only half their length, the rima glottidis being partly closed; and this explanation is consistent with the fact, that a far smaller quantity of air is required for sustaining a falsetto note, than for a note of the ordinary register, even though they should be of the same pitch. By Müller, again, it is asserted that in the production of the falsetto notes, merely the thin border of the glottis vibrates, so that the fissure remains distinctly visible; whilst, in the production of the ordinary vocal tones, the whole breadth of the vocal ligaments is thrown into strong vibrations, which traverse a wider space, so that a confused motion is seen in the lips of the glottis, rendering its fissure indefinite. It is not impossible that both these doctrines may be correct; and that, in the production of falsetto notes, the vocal ligaments are in contact with each other for part of their length, their thin edges only being in vibration in

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* Thus a gentleman of the Author's acquaintance has a bass voice of a harsh reedy character, ranging from the D below the bass cleff to the D above it (two octaves); whilst his falsetto, which is remarkable for its clearness and smoothness, ranges from the A on the highest line of the bass cleff to the E in the highest space of the treble cleff. Hence there are five notes common to the two registers, and the entire voice ranges through more than three octaves; but from want of a gradual passage from one to the other, this gentleman can only sing bass parts with his chest-voice, or alto parts with his falsetto, the tenor scale extending above the range of one, and below that of the other.

the remainder. It has been pointed-out by Mr. Bishop (loc. cit.), that at the moment of transition from the 'chest-voice' to the 'falsetto-voice,' the crico-thyroid chink, which was closed during the production of the highest note of the former, suddenly opens on the production of the lowest note of the latter; thus indicating that the Vocal Cords are *relaxed* in the passage from the one to the other, as must be the case, if, for the production of the same note, they be only put in vibration along a part of their length; so that it would not seem improbable that the cause of those differences in the mode of transition which have been already noticed, lies in the differences in the proportional amount of the vocal cords, which is thus thrown-out of use by the partial approximation of the two lips of the rima glottidis. It is further remarked by Mr. Bishop, that, in the passage from the chest- to the falsetto-voice, the larynx descends from its previously-elevated position, and gradually rises again with the ascending scale of falsetto notes; and he mentions a case of *double falsetto*, in which a third register existed, and in which the relaxation of the Vocal cords and the descent of the larynx were observed at its commencement, as at the commencement of the second or ordinary falsetto register.—An entirely different theory of the falsetto has been given, however, by MM. Pétrequin and Diday;* who consider that the falsetto notes are not produced by the vibration of the vocal cords, but are really 'flute-notes,' formed by the vibrations of the column of air to which the rima glottidis then serves as the embouchure. This view harmonizes well with some of the phenomena of the falsetto-voice; but it is open to the objections already stated in regard to the flute-theory generally. According to M. Garcia, again,† in the production of the falsetto-register the external fibres of the lateral crico-arytenoid muscle remain inactive, whilst the lips of the glottis, stretched by the horizontal bundle of the thyro-arytenoid, come in contact by their edge alone, and offer little resistance to the air. In the chest-voice, on the contrary, the contraction of the lateral crico-arytenoids gives a rotatory movement to the cartilages, and increases the depth of the surface of contact of the two ligaments, and it is to this circumstance that the peculiar amplitude of the notes of the chest-register is attributable. It may be added that some have attempted to show, that the falsetto depends upon a peculiar action of the parts *above* the larynx; but for this doctrine there is no foundation whatever.—The pressure of the air within the Trachea during the production of voice is considerable. Cagniard Latour observed in a man with a tracheal fistula, that the pressure indicated by a manometer when the patient called out at the top of his voice, was equal to a column of water 38 inches in height; when he spoke at his usual pitch, to one of 5 inches; and when he sang a high note, to one of about 8 inches The deepest notes the human Larynx is capable of producing have about 80 double vibrations in the second, the highest about 992; the former occurring in bass, the latter in soprano voices.

690. The various muscular actions which are employed in the production and regulation of the Voice, are called-forth by an impulse which has been shown (§§ 525, 530) to be really *automatic* in its operation, and to be completely under the influence of guiding sensations, although usually originating in a Volitional determination, or giving expression to

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* "Gazette Médicale," 1844. † "Proceedings of the Royal Society," vol. vii. p. 408.

Emotions or simply to Ideas. This, however, has been proved to be also true of *all* Volitional movements; so that the production of vocal tones constitutes no real exception. It may be safely affirmed, that the simple utterance of sounds is in itself an Instinctive action; although the combination of these, whether into music or into articulate language, is a matter of acquirement, which is much more readily made by some individuals than by others. No definite tone can be produced by a Voluntary effort, unless that tone be present to the consciousness during an interval—however momentary,—either as immediately produced by an act of Sensation, recalled by an act of Conception, or anticipated by an effort of the Imagination. When thus present, the Will can enable the muscles to assume the condition requisite to produce it; but under no other circumstances does this happen, except through the particular mode of discipline by which the congenitally-deaf may be trained to speak. Such persons are debarred from learning the use of Voice in the ordinary manner; for the necessary guidance cannot be afforded, either through sensations of the present or conceptions of the past, and the imagination is entirely destitute of power to suggest that which has been in no shape experienced. But they may be taught to acquire an imperfect speech, by causing them to imitate particular muscular movements, which they may be made to see; being guided in the imitation of those movements, in the first place by watching their own performance of them in a looking-glass, and afterwards by attending to the muscular sensations which accompany them. Many instances, indeed, are on record, in which persons entirely deaf were enabled to carry-on a conversation in the regular way; judging of what was said by the movements of the lips and tongue, which they had learned to connect with particular syllables; and regulating their own voices in reply, by their voluntary power, guided in its exercise by their muscular sensations.*

2. *Of Articulate Sounds.*

691. The larynx, as now described, is capable of producing those *tones* of which Voice fundamentally consists, and the sequence of which becomes Music: but *Speech* consists in the modification of the laryngeal tones, by other organs intervening between the Glottis and the Os externum, so as to produce those *articulate sounds* of which language is formed. It cannot be questioned that Music has its language; and that it is susceptible of expressing Emotional states of the mind (among those, at least, who have been accustomed to associate these with its varied modes) to even a higher degree than articulate speech. But it is incapable of addressing the Intellect, by conveying definite ideas of objects, properties, actions, &c., in any other way than by a kind of imitation, which may be compared to the signs used in hieroglyphic writing. These ideas it is the peculiar province of Articulate Language to convey; and we find that the vocal organ is adapted to form a large number of simple sounds, which may be readily combined into groups, forming words. The number of combinations which can be thus produced is so inexhaustible, that every language has its own peculiar series; no difficulty being found in forming new ones to express new ideas. There is considerable diversity in different languages, even with regard to the use of the simplest of these combinations; some of them are more easy of formation than others, and

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* See Dr. Johnstone "On Sensation," p. 128.

these accordingly enter into the composition of all languages; whilst of the more difficult ones, some are employed in one language, some in another,—no one language possessing them all. Without entering into any detailed account of the mechanism required to produce each of these simple sounds, a few general considerations will be offered in regard to the classification of them; and the peculiar defect of articulation termed *Stammering* will be briefly treated-of.

692. Vocal sounds are divided into Vowels and Consonants; and the distinctive characters of these are usually considered to be, that the Vowels are produced by the Voice alone, whilst the sound of the Consonant is formed by some kind of interruption to the voice, so that they cannot be properly expressed unless conjoined with a vowel. The distinction may be more correctly laid-down, however, in this manner:—the Vowel-sounds are continuous tones, modified by the form of the aperture through which they pass-out; whilst in sounding Consonants, the breath suffers a more or less complete interruption in its passage through parts anterior to the larynx. Hence the really-simple Vowel-sounds are capable of prolongation during any time that the breath can sustain them; this is not the case, however, with the real Diphthongal sounds (of which it will presently appear that the English *i* is one); whilst it is true of some Consonants. It seems to have been forgotten by many of those who have written upon this subject, that the laryngeal voice is not essential to the formation of either vowels or consonants; for all may be sounded in a whisper. It is very evident, therefore, that the larynx is not primarily concerned in their production; and this has been fully established by the following experiment. A flexible tube was introduced by M. Deleau through his nostril into the pharynx, and air was impelled by it into the fauces; then, closing the larynx, he threw the fauces into the different positions requisite for producing articulate sounds, when the air impelled through the tube became an audible whisper. The experiment was repeated, with this variation,—that the laryngeal sounds were allowed to pass into the fauces; and each articulated letter was then heard double, in a proper voice and in a whisper.

693. That the Vowels are produced by simple modifications in the form of the external passages, is easily proved both by observation and by imitative experiment. When the mouth is opened wide, the tongue depressed, and the velum palati elevated, so as to give the freest possible exit to the voice, the vowel *a* in its broadest form (as in *ah*) is sounded.* On the other hand, if the oral aperture be contracted, the tongue being still depressed, the sound *oo* (the continental *u*) is produced. If attention be paid to the state of the buccal cavity, during the pronunciation of the different vowel-sounds, it will be found to undergo a great variety of modifications, arising from varieties of position of the tongue, the cheeks, the lips, and velum palati. The position of the tongue is, indeed, one of the primary conditions of the variation of the sound; for it may be easily ascertained that, by peculiar inflexions of this organ, a great diversity of vowel-sounds may be produced, the other parts remaining the same. Still there is a certain position of all the parts, which is most favourable

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* This sound of the vowel *a* is scarcely used in our language, though very common in most of the Continental tongues; the nearest approach to it in English is the *a* in *far;* but this is a very perceptible modification, tending towards *au.*

to the formation of each of these sounds; but this could not be expressed without a lengthened description. The following table, slightly altered from that of Kempelen, expresses the relative dimensions of the buccal *cavity* and of the oral *orifice* for some of the principal of these; the number 5 expressing the largest size, and the others in like proportion:—

Vowel.	*Sound.*	*Size of oral opening.*	*Size of buccal cavity.*
a	as in *ah*	5	5
a	as in *name*	4	2
e	as in *theme*	3	1
o	as in *cold*	2	4
oo	as in *cool*	1	5

These are the sounds of the five vowels, *a*, *e*, *i*, *o*, *u*, in most Continental languages; and it cannot but be admitted that the arrangement is a much more natural one than that of our own vowel series. The English *a* has three distinct sounds capable of prolongation;*—the true broad *a* of *ah*, slightly modified in *far*; the *a* of *fate*, corresponding to the *e* of French; and the *a* of *fall*, which should be really represented by *au*. This last is a simple sound, though commonly reckoned as a diphthong. In Kempelen's scale, the oral orifice required to produce it would be about 3, and the size of the buccal cavity 4.† On the other hand, the sound of the English *i* cannot, like that of a true vowel, be prolonged *ad libitum*; it is in fact a sort of diphthong, resulting from the transition from a peculiar indefinite murmur to the sound of *e*, which takes its place when we attempt to continue it. The sound *oy* or *oi*, as in *oil*, is a good example of the true diphthong; being produced by the transition from *au* to *e*. In the same manner, the diphthong *ou*, which is the same with *ow* in owl, is produced in the rapid transition from the broad *a* of *ah*, to the *oo* of cool.—Much discussion has taken-place as to the true character of *y*, when it commences a word, as in yet, yawl, &c.; some having maintained that it is a consonant (for the very unsatisfactory reason that we are in the habit of employing *a* rather than *an*, when we desire to prefix the indefinite article to such words), whilst others regard it as a peculiar vowel. A slight attention to the position of the vocal organs during its pronunciation, makes it very clear that its sound in such words really corresponds with that of the long (English) *e*; the pronunciation of the word yawl being the same as that of ēaul, when the first sound is not prolonged, but rapidly transformed into the second. The sound of the letter *w*, moreover, is really of the vowel character, being formed in the rapid transition from *oo* to the succeeding vowel; thus *wall* might be spelt *ŏŏal*. Many similar difficulties might be removed, and the conformity between spoken and written language might be greatly increased (so as to render far more easy the acquirement of the former from the latter), by due attention to the state of the vocal organs in the production of the simple sounds.

694. It is not very difficult to produce a tolerably good artificial imita-

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* The *short* vowel sounds, as *a* in fat, *e* in met, *o* in pot, &c., are not capable of prolongation.

† The mode of making a determination of this kind may here be given, for the sake of example. If the broad *a* be sounded, the mouth and fauces being opened wide, and we contract the oral orifice by degrees, at the same time slightly elevating the point of the tongue, we gradually come to the sound of *au*; by still further contracting the orifice, and again depressing the tongue, we form *oo*. On the other hand, in sounding *e*, the tongue is raised nearly to the roof of the mouth; if it be depressed, without the position of the lips being altered, *au* is given.

tion of the Vowel-sounds. The method adopted by Helmholtz of combining the fundamental note with various harmonics for each vowel has been already referred to (§ 629). By Kempelen it was accomplished by means of an India-rubber ball, with an orifice at each end, of which the lower one was attached to a reed: by modifying the form of the ball, the different vowels could be sounded during the action of the reed. He also employed a short funnel-like tube, and obtained the different sounds by covering its wide opening to a greater or less extent. This last experiment has been repeated by Mr. Willis; who has also found that the vowel sounds might be imitated, by drawing-out a long straight tube from the reed. In this experiment he arrived at a curious result:—with a tube of a certain length, the series of vowels, *i*, *e*, *a*, *o*, *u*, was obtained by gradually drawing it out; but if the length was increased to a certain point, a further gradual increase would produce the same sequence in an inverted order, *u*, *o*, *a*, *e*, *i;* a still further increase would produce a return to the first scale, and so on. When the pitch of the reed was high, and the pipe short, it was found that the vowels *o* and *u* could not be distinctly formed, —the proper tone being injured by the elongation of the pipe necessary to produce them; and this, Mr. Willis remarks, is exactly the case in the Human voice, most singers being unable to pronounce *u* and *o* upon their highest notes.

695. The most natural primary division of the Consonants, is into those which require a total stoppage of the breath at the moment previous to their being pronounced, and which, therefore, cannot be prolonged; and those in pronouncing which the interruption is partial, and which can, like the vowel-sounds, be prolonged *ad libitum*. The former have received the designation of *explosive;* and the latter of *continuous*.—In pronouncing the *explosive* consonants, the posterior nares are completely closed, so that the exit of air through the nose is altogether prevented; and the current may be checked in the mouth in three ways,—by the approximation of the lips,—by the approximation of the point of the tongue to the front of the palate,—and by the approximation of the middle of the tongue to the arch of the palate. In the first of these modes, we pronounce the letters *b* and *p;* in the second *d* and *t;* in the third, the hard *g* and *k*. The difference between *b*, *d*, and *g*, on the one hand, and *p*, *t*, and *k*,* on the other, seems to depend on this;—that in the former group the approximating surfaces are larger, and the breath is sent through them more strongly at the moment of opening, than in the latter. The *continuous* consonants may be again subdivided, according to the degree of freedom with which the air is allowed to make its exit, and the compression which it consequently experiences. I. The first class includes those in which no passage of air takes-place through the nose, and in which the parts of the mouth that produce the sound are nearly approximated together, so that the compression is considerable. This is the case with *v* and *f*, which are produced by approximating the upper incisors to the lower lip, and which stand in nearly the same relation to each other as that which exists between *d* and *t*, or *b* and *p*. The sibilant sounds, *z* and *s*, also stand in a similar relation to each other; they are produced by the passage of air between the point of the tongue and the front of the palate, the teeth being at the same time nearly closed. The simple sound *sh* is formed, by narrowing the channel between the dorsum of the tongue

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* For the sake of proper comparison, this letter should be sounded not as *kay* but *key*.

and the palate; the former being elevated towards the latter through a considerable part of its length. If, in sounding *s*, we raise the point of the tongue a very little, so as to touch the palate, the sound of *t* is evolved; and in the same manner *d* is produced from *z*. This class also includes the *th;* which, being a perfectly-simple sound, ought to be expressed by a single letter, as in Greek, instead of by two, whose combination does not really produce anything like it. For producing this sound, the point of the tongue is applied to the back of the incisors, or to the front of the palate, as in sounding *t;** but whilst there is complete contact of the tip, the air is allowed to pass-out around it.—II. In the second class of continuous consonants, including the letters *m*, *n*, *l*, and *r*, the nostrils are not closed; and the air thus undergoes very little compression, even though the passage of air through the oral cavity is almost or completely checked. In pronouncing *m* and *n*, the breath passes through the nose alone: and the difference of the sound of these two letters must be due to the variation in the form of the cavity of the mouth, which acts by resonance. The letter *m* is a labial, like *b;* but in the former the nasal passage is open, the mouth remaining closed, whilst in the latter the nose is entirely closed, and the sound is formed at the moment of opening the mouth; hence the passage from *m* to *b* is made with great facility. The same correspondence exists between *n* and *t*, or *n* and *g* (the particular part of the tongue approximated to the palate not being of much consequence in the pronunciation of *n*); and hence it is that the transition from *n* to *t*, or from *n* to *g*, is so easy that the combinations *nt* and *ng* are found abundantly in most languages. The sound of *l* is produced by bringing the tip of the tongue into contact with the palate, and allowing the air to escape around it, at the same time that a vocal tone is generated in the larynx; it differs therefore from *th* in the position at which the obstruction is interposed, as well as in the slight degree of compression of the air which it involves. The sound of the letter *r* depends on an absolute vibration of the point of the tongue, in a narrow current of air forced between the tongue itself and the palate.—III. The sounds of the third class are scarcely to be termed consonants, since they are merely *aspirations* caused by an increased force of breath. These are *h*, and the gutteral *ch*† of most foreign languages (the Greek χ). The first is a simple aspiration; the second an aspiration modified by the elevation of the tongue, causing a slight obstruction to the passage of air, and an increased resonance in the back of the mouth. This sound would become either *g* or *k*, if the tongue, whilst it is being produced, were carried-up to touch the palate.‡

696. These distinctions come to be of much importance, when we apply ourselves to the treatment of defects of articulation. Great as is the number of muscles employed in the production of definite vocal sounds, the number is much greater for those of articulate language; and the varieties of combination which we are continually forming uncon-

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* Hence it is easy to understand the substitution of *t* or *d*, for the English *th*, by foreigners.

† The English *ch* is merely a combination of *t* with *sh;* thus *chime* might be spelt *tshime*.

‡ The general classification proposed by Dr. Marshall Hall has been here adopted, with some modification as to the details.

sciously to ourselves, would not be suspected without a minute analysis of the separate actions. Thus, when we utter the explosive sounds, we check the passage of air through the posterior nares in the very act of articulating the letter; and yet this important movement commonly passes unobserved.—We must regard the power of forming the several articulate sounds which have been adverted-to, and their simple combinations, as so far resulting from intuition, that it can in general be more readily acquired by early practice than other actions of the same complexity: but we find that among different Races of Men, there exist tendencies to the production of different sounds, which, though doubtless influenced in great degree by early habit (since we find that children, when first learning to speak, form their habits of vocalization in great degree in accordance with the examples amidst which they are placed), are certainly also dependent in part upon congenital constitution; as we often see in the case of children among ourselves, who grow-up with certain peculiarities of pronunciation, not thus derived from imitation, of which they do not seem able to divest themselves.

697. It is in the want of power to *combine* the different muscular actions concerned in vocalization, that the defect termed *Stammering* essentially consists. Many theories regarding the nature of this impediment have been proposed; and there can be little doubt that it may be attributed to a great variety of exciting causes. A disordered action of the nervous centres must, however, be regarded as the proximate cause; though this may be (to use the language of Dr. M. Hall) either of *centric* or of *excentric* origin,—that is, it may result from a morbid condition of the ganglionic centre, or from an abnormal impression conveyed through its afferent nerves. When of centric origin (and this is probably the most general case), the phenomena of Stammering and Chorea have a close analogy to each other; in fact, stammering is frequently one of the modes in which the disordered condition of the nervous system in Chorea manifests itself.—It is in the pronunciation of the Consonants of the *explosive* class, that the stammerer experiences the greatest difficulty. The total interruption to the breath which they occasion, frequently becomes quite spasmodic;* and the whole frame is thrown into the most distressing semi-convulsive movement, until relieved by expiration. In the pronunciation of the *continuous* Consonants of the first class, the stammerer usually prolongs them by a spasmodic continuance of the same action; and there is, in consequence, an impeded, but not a suspended respiration. The same is the case with the *l* and *r* in the second class. In pronouncing the *m* and *n*, on the other hand, as well as the aspirates and vowels, it is sometimes observed that the stammerer prolongs the sound by a full and exhausting expiration. In all these cases, then, it seems as if the muscular sense resulting from each particular combination of actions, became the stimulus to the involuntary prolongation of that state. It is possible that the defect may result, in some instances, from malformation of the parts about the fauces, producing an abnormal stimulus of this kind in some particular positions of the organ; and such cases *may be* really benefited by an operation for the removal of these

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* By Dr. Arnott this interruption is represented as taking place in the larynx; that such is not usually the case, the Author believes that a little attention to the ordinary phenomena of voice will satisfactorily prove.

parts. But the effect of such an operation is certainly exerted in most cases through the *mind* of the patient; the expectation of benefit from it tending to improve his command over the muscles of vocalization, which Emotional excitement always impairs; and the improvement is usually proportional to the confidence which he has been led to feel in the result. The slightest disturbance of the feelings is sufficient in most Stammerers to induce a complete perturbation of the vocal powers; the very fear that stammering will occur, particularly under circumstances which render it peculiarly annoying, is often sufficient to bring it on in a predisposed subject; and the tendency to consensual imitation sometimes occasions stammering, in individuals (especially children) who never show the slightest tendency to it except when they witness the difficulty in others.

698. The method proposed by Dr. Arnott for the prevention of Stammering, consists in the connection of all the words by a vocal intonation, in such a manner that there shall never be an entire stoppage of the breath. It is justly remarked by Müller, however, that although this plan may afford some benefit, it cannot do everything; since the main impediment occurs in the middle of words themselves. One important remedial means, on which too much stress cannot be laid, is to study carefully the mechanism of the articulation of the difficult letters, and to practise their pronunciation repeatedly, slowly, and analytically. The patient would at first do well to practise sentences from which the explosive consonants are omitted; his chief difficulty, arising from the spasmodic suspension of the expiratory movement, being thus avoided. Having mastered these, he may pass-on to others, in which the difficult letters are sparingly introduced; and may finally accustom himself to the use of ordinary language. One of the chief points to be aimed-at, is to make the patient feel that he *has* command over his muscles of articulation; and this is best done, by gradually leading him from that which he finds he *can* do, to that which he fears he *cannot*. The fact that stammering people are able to *sing* their words better than to *speak* them, has been usually explained on the supposition that, in singing, the glottis is kept open, so that there is less liability to spasmodic action; if, however, as here maintained, the spasmodic action is not in the larynx, but in the velum palati and the muscles of articulation, the difference must be due to the direction of the attention rather to the muscles of the larynx than to those of the mouth.—One of the most important objects to be aimed-at in the treatment of stammering, consists in the prevention of all Emotional disturbance in connection with the act of Speech; and this requires the exercise of the Voluntary power over the direction of the thoughts, in the following modes:—1. To *reduce* mental emotion, by a daily, hourly, habit of abstracting the mind from the subject of stammering, both while speaking, and at other times. 2. To *avoid exciting* mental emotion by attempting unnecessarily to read or speak, when the individual is conscious that he shall not be able to perform these actions without great distress. 3. To *elude* mental emotion, by taking advantage of any little artifice to escape from stammering, so long as the artifice continues to be a successful one.—Much may frequently be done, also, by constitutional treatment, adapted to improve the general vigour of the nervous system.*

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* See on the subject of "Stammering and its Treatment," a useful pamphlet under

CHAPTER XV.

OF THE INFLUENCE OF THE NERVOUS SYSTEM ON THE ORGANIC FUNCTIONS.

699. Of the modes in which the Nervous System influences the Organic Functions, a great part have been already considered; for it has been shown to be concerned in providing the mechanical conditions, either immediate or remote, under which alone these functions can be performed; so that, when its activity ceases, they cannot be much longer maintained. But the influence of the Nervous System is not alone exerted upon the motor or contractile tissues of the body; for there is good evidence that it has a direct operation upon the molecular changes which constitute the functions of Nutrition, Secretion, &c.; and this view may be admitted to its fullest extent, without our being thereby led to regard the processes in question as *dependent* upon Nervous agency,—a doctrine for which there seems no valid foundation. Throughout the Animal body, it may be observed that, the more Vegetative the nature of any function, the less is it under the influence of the Nervous System, save where that influence is required to bring it into harmony with other functions, sometimes by exciting, sometimes by checking, and sometimes by otherwise modifying them, very much in the way that a rider guides and controls the movements of his horse.—It is evident that this influence must be principally exerted through the *Sympathetic* or *Visceral* system of nerves, since a large proportion of the organs on which it operates are supplied by no other: and hence this apparatus has been commonly designated the 'Nervous system of *organic* life,' as distinguishing it from the Cerebro-spinal system, which is the 'Nervous system of *animal* life.' There is, however, no such parallelism between them as this designation would imply; for whilst the operations of the Cerebro-spinal system *essentially constitute* the Animal life of the individual, those of the Sympathetic cannot be fairly said to do more than *control* and *direct* those of Nutrition and Secretion.—We shall now inquire into the structure and relations of the Sympathetic System; and shall then examine the nature of the actions which there seems reason to attribute to it.

700. *Sympathetic Nervous System.*—That collection of scattered but mutually-connected ganglia and nerves, of which this apparatus is made up, may be ranged under the following groups:—1. The isolated ganglia and nerves in immediate connection with the Viscera, which seem to be the chief centres of the system; these form three principal plexuses, the *Cardiac*, the *Solar*, and the *Hypogastric*. 2. The double chain of *Pre-vertebral* ganglia, with connecting cords, which lies in front of the Vertebral column, and which communicates on the one hand with the Spinal

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this title, by Bacc. Med. Oxon., 1850; and Mr. Bishop's treatise "On and on the Causes and Cure of Impediments of Speech."

nerves, and on the other with the before-named plexuses. Under this head we should probably rank the minute Cranial ganglia, which are situated in the neighbourhood of the Organs of Sense, and in immediate connection with the branches of the Fifth pair that proceed to them; these are the *ophthalmic*, *otic*, *spheno-palatine*, and *submaxillary* ganglia. 3. The *ganglia on the posterior roots* of the Spinal nerves; under which head we are probably to rank not only the *Gasserian* ganglion of the Fifth pair, but also the ganglia near the roots of the Pneumogastric and Glosso-pharyngeal nerves.—The trunks of the Sympathetic are made-up of different orders of fibres; some of these having their central termination in the vesicular matter of the Sympathetic ganglia themselves, whilst others are derived from the Cerebro-spinal system. The former, which are all of the 'gelatinous' kind,* are most abundant in the great Visceral plexuses; but they may be traced from the prevertebral ganglia into the Spinal nerves, part of them proceeding to the ganglia on their posterior roots (whence fibres are given-off that mingle with their spinal fibres), whilst another part enter the anterior roots and mingle with *their* fibres. On the other hand, the latter, which are of the 'tubular' kind, are derived by the same cords of communication (these being commonly termed the 'roots' of the Sympathetic, but being really commissural bands that bring the two systems into connection) from both roots of the Spinal nerves, and pass through the prevertebral ganglia into the Sympathetic system, without undergoing any ostensible change. Thus it appears that the Cerebro-spinal and Sympathetic systems *interpenetrate* one another; each having its own series of ganglionic centres, and of trunks connected with them; but each system transmitting its fibres into the trunks of the other, so as to be peripherally distributed with their ramifications.

701. The distribution of the principal trunks and branches of the Sympathetic system may be concisely stated as follows:—1. Those of the *Cardiac* plexus proceed chiefly to the Heart and great blood-vessels, whence they are continued, with reinforcements derived-from other subdivisions, and with multitudes of minute ganglia in their course, along the ramifications of the Vascular system throughout the body, embracing them as ivy embraces the trunk and branches of a tree. Those of the *Solar* plexus are transmitted in part to the muscular walls of the Alimentary canal, from the stomach to the lower end of the colon; in part to the principal arterial branches given-off from the aorta, and with them to the liver, pancreas, spleen, and kidneys, as also to the testes of the male and the ovaries of the female. Those of the *Hypogastric* plexus supply the muscular walls of the pelvic viscera, the bladder, urethra, vagina of the female, and rectum; besides sending branches to the blood-vessels themselves.—2. The branches of the *Prevertebral* ganglia of the trunk for the most part contribute to form the plexuses just described. Those of the neck, however, furnish a large supply to the carotid artery, round which they form a plexus, and also give-off branches which inosculate with those of the Pneumogastric to form the pharyngeal and laryngeal plexuses; and those of the upper part of the thorax give-off branches which inosculate with those of the Pneumogastric to form the

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* It must be carefully borne in mind, that, although the proper Sympathetic fibres are all 'gelatinous,' yet that the Cerebro-Spinal system contains 'gelatinous' fibres of its own, which are very abundant in some parts.

pulmonary plexus. Of the *ophthalmic* ganglion (§ 477), the branches are distributed, not merely to the iris, whose radiating fibres are made to contract through their instrumentality, as already explained (§ 608); but also to the vascular apparatus of the eyeball, and especially to the ciliary processes, which seem to possess a sort of erectile character. The *otic* ganglion, which communicates with the third division of the Fifth pair and with the Glosso-pharyngeal, may be considered, from the distribution of most of its branches to the tensor tympani and circumflexus palati muscles, as ministering to the exercise of the sense of Hearing, in somewhat the same mode that the ophthalmic ganglion seems to do to that of vision (§ 632). The *spheno-palatine* ganglion (Fig. 129, *f*), whose connections are with the Fifth and the Facial nerves, seems in like manner to minister, by the distribution of its branches on the mucous membrane of the nasal cavity and the palate, to the senses of Smell and Taste. Of the *submaxillary* ganglion, which also is chiefly connected with the Fifth and the Facial nerves, the branches proceed almost entirely to the Submaxillary gland.—3. The fibres which arise from the ganglia on the posterior roots of the Spinal nerves (if really belonging to the Sympathetic system) must be distributed along with the branches proceeding from the trunks which they help to form; as must also a part of those fibres which are sent from the proper Sympathetic ganglia into the roots of the same nerves, a large part of them, however, being distributed upon the blood-vessels of the Spinal Cord itself.

702. If, then, it be inquired what inferences we are entitled to draw respecting the functions of the Sympathetic system of nerves, from our knowledge of its Anatomical distribution, we are at once justified in replying, that a large proportion of the Muscular apparatus which directly ministers to the Organic functions,—that, namely, which surrounds the alimentary canal from the stomach downwards, with the gland-ducts which open into it,—that, also, which forms the walls of the bladder and uterus, of the ureters and Fallopian tubes,—and that, too, which governs the diameter of the blood-vessels,—*receives no other nervous supply*; and, consequently, that whatever motor influence these parts may receive from Mental states or from excitation not applied to themselves, this system of nerves must be the channel. The same may be said, too, in regard to that greater portion of the Glandular apparatus, which is exclusively supplied by the Sympathetic nerve, and chiefly by the plexuses that embrace its blood-vessels; since any such alterations in its rate of activity, or in the character of its products, as depend upon conditions of Mind, can be brought-about through no other instrumentality.—It is not a little remarkable, however, that those portions of the Muscular apparatus of Organic life, which most obviously exhibit in their action the influence of the Nervous system, both in their respondence to emotional states and in their 'sympathy' with disturbance in other functions,—namely, the Heart and the Stomach,—derive a considerable part of their nervous supply directly from the Cerebro-spinal system. And it is still more significant, that most of those Glands whose function is occasional, and whose states of activity are most obviously influenced by affections of the Mind, are specially supplied by Cerebro-spinal nerves, in addition to the Sympathetic plexuses which they receive on the walls of their blood-vessels: thus, the Lachrymal and Salivary glands are supplied with

branches of the Fifth and Facial nerves; and the Mammary glands by branches of the Intercostals. It cannot but be deemed highly probable, then, from this circumstance alone, that the influence of mental states upon the function of Secretion may be exerted through the nerves of the Cerebro-spinal system, as well as through those of the Sympathetic.

703. It must be in virtue of the connections of the Sympathetic with the Cerebro-spinal system, that the parts which are solely supplied with nerves from the former, are capable of transmitting sensory impressions to the Sensorium. It is true that, under ordinary circumstances, these parts are insensible; that is, impressions made upon them do not travel onwards through the Spinal Cord to the Encephalon: but their sensibility is acutely manifested in morbid states, in which the impressions seem to be propagated further than usual, in virtue of their greater potency. That it is the office of the ganglia on the roots of the Spinal nerves to "cut-off sensation," that is, to prevent the further transmission of sensory impressions, is an old doctrine; and there seems much reason to believe that this may be effected by the free communication between one fibre and another, which is established through the vesicular substance of a ganglion, so that the whole force of ordinary impressions on the nerve-fibres is lost in diffusion among the rest of their contents. The same principle seems to apply to the motor fibres; for there are cases which show that when fibres obviously belonging to Cerebro-spinal nerves pass through Sympathetic ganglia, they do not so rapidly or so surely transmit motor impulses, as when they have no such relation to ganglia.*

704. Although it is not easy to obtain definite evidence of the influence of the Sympathetic system on *Muscular Contraction*, since this influence is extinguished within a short time after death, yet it has been established by the elaborate researches of Prof. Valentin and others† (§§ 74, 216, 227), that contractions of the various muscular parts supplied by the three great Visceral plexuses may be excited by irritation applied to their nerves and ganglia. But Prof. V. has further shown, that the same effects may be produced by irritating either the Prevertebral ganglia, or the cords of communication with the Spinal nerves which have been sometimes called the 'roots' of the Sympathetic, or the roots of the Spinal nerves themselves. It results from his inquiries, that, although any particular division of the Sympathetic nerve must be regarded as extremely complex in its relations, deriving its motor fibres from many different sources, the ultimate distribution of these fibres is sufficiently simple, so that each organ is definitely supplied from a certain part of the Cerebro-spinal axis. But the fibres proceeding from the roots of the Cerebro-spinal nerves do not pass into the *nearest* organs, being transmitted through three or more of the prevertebral ganglia of the Sympathetic, before reaching their ultimate destination; thus the motor fibres of the cardiac plexus are principally derived from the cervical portion of the Spinal Cord, those of the solar plexus from the thoracic region, and those of the hypogastric plexus from the dorsal region. So, again, we have seen that the dilatation of the Pupil, which immediately depends on the

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* See Messrs. Kirkes and Paget's "Handbook of Physiology," p. 420.

† As by Ludwig, see "Sitzungsber. d. Wien. Akad.," 1857; Biffi, see Meissner's "Jahresbericht," 1858; Budge, "Untersuchungen über das Nerven System," band i.; Schiff, "Comptes Rendus," 1860 and 1862; C. Bernard, "Comptes Rendus," 1862.

instrumentality of the Sympathetic nerve, is called-forth also by irritation of the roots of the Spinal nerves in the cervical region (§ 639).

705. The effects of section and of galvanization of the cut extremities of the Sympathetic nerve in the neck, have been carefully investigated by Bernard, Waller, Brown-Séquard* and others. On dividing the nerve, the blood-vessels of that side of the head dilate, and with the freer current of blood which is there established through the capillaries, an increase of the vital properties of all the tissues on the same side of the head is associated. Thus the sensibility of the retina for light appears to be augmented, whence follow contraction of the pupil, retraction of the globe of the eye, partial closure of the eyelid, and projection of the *membrana nictitans* (where present) with increased flow of tears. The temperature and sensibility of the skin, and the cutaneous secretions, are also much increased,—the temperature in some of Dr. Waller's experiments† rising as much as 18° Fahr., and the skin in some of M. Bernard's being bathed with perspiration. The colour of the venous blood assumes a brighter hue, and its coagulation is more rapid. The muscles respond more readily to weak, and more energetically to strong stimuli, and retain their irritability longer; rigor mortis consequently setting in more slowly and enduring for a longer period; whilst it further appears from Snellen's researches‡ that even the inflammatory and reparative processes, as the effusion of serum, the formation of pus, the absorption of effused blood, and the cicatrization of wounds, take place with very much greater energy and rapidity. On the contrary, when the upper cut extremity of the nerve is galvanized, all these phenomena are reversed; for now, as a consequence of the contraction of the blood-vessels and the diminished supply of blood which ensues, the vital properties of the tissues are diminished, the pupil dilates, the eyelid is widely opened, the temperature and sensibility of the parts decrease, the contractile power of the muscles is less strongly marked, their normal galvanic current is feeble, and cadaveric rigidity sets-in quickly and soon passes off, putrefaction immediately supervening. The effects produced by section of the Sympathetic in the neck are much more strongly marked when the cervical ganglia are destroyed, and Bernard§ states that closely similar results follow section of the Sympathetic nerves distributed to the vessels of the extremities. In these later experiments he found that division of the roots of the spinal nerves within the spinal canal, though abolishing sensation and motion in the limb beyond, yet produced no effect upon its temperature; whilst if after such section the sciatic or brachial nerves were divided, an immediate exaltation of temperature ensued; clearly showing that the nerve-fibres devoted to the conduction of sensory and motor impulses issuing from the spinal cord had been joined by a third set of fibres, either proceeding directly from the sympathetic ganglia, or through and beyond these from some part of the cerebro-spinal system, the office of which is to preside over the contraction of the vessels and calorification. A further corroboration of this view was obtained by experiments in which the lumbar ganglia of the Sympathetic were destroyed,

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* See "Lectures on the Central Nervous System," 1860, lectures ix. and x.

† "Comptes Rendus," 1853. ‡ Henle and Meissner's "Bericht," 1857, p. 373.

§ See "Gazette Hebdomad.," Août, 1862; "Comptes Rendus," vol. ii. 1862; and "Journal de la Physiologie," vol. v.

when the vascular changes and the increase of temperature in the lower limb were observed without the occurrence of any paralysis. Dr. Waller* has shown that some of the results of irritation of the cervical portion of the sympathetic may be made apparent during life by pressure of the point of the finger behind the ramus of the jaw, though they are associated with other phenomena proceeding from irritation of the pneumogastric. The more important symptoms observed were dyspnœa, cardiac and gastric disturbance, tingling and heat of the ear, lasting for upwards of half an hour, and in one instance dilatation followed by contraction of the pupil. Dr. Waller† has also ingeniously shown the effects of paralysis of the vasomotor nerves of the arm in the living body, by applying a freezing mixture to the ulnar nerve at the elbow; the effect in the first instance being to produce a fall of temperature equal to about 0·5° C. in the two inner fingers; but as the vasomotor nerves became paralysed, the temperature gradually rose till it attained a height of from 5° to 6° C. above that of the outer fingers: the difference between the outer and inner fingers appeared to be partially attributable to a decrease in the temperature of the former as well as to an increase in that of the latter, owing to the diversion of part of the blood of the radial into the ulnar artery.

706. It is a point of great difficulty to determine whether the dilatation of the vessels of any part which follows paralysis or section of the Sympathetic nerves is simply *passive*; or whether some agency works here, as in the so-called inhibitory influence of the pneumogastric nerves upon the heart, and of the splanchnic nerves upon the small intestine, to produce relaxation of the muscular fibres, and a consequent *active* dilatation of the vessels. M. Bernard, who supports the latter opinion, refers to the experiments already alluded-to on the salivary glands and their nerves (§ 80), as showing that, besides the influence conducted by the sympathetic cords and inducing contraction of the muscular walls of the vessels distributed to those glands, an active dilating power proceeding from cerebro-spinal centres is exerted upon them, inducing an instantaneous increase in the flow of blood through the vessels; and Schiff observes that if the skin of the ear of a rabbit be lightly tickled, a local dilatation immediately follows in the arterial trunks supplying that part, which will take place even if the superior cervical sympathetic ganglion have been previously excised, or the cord of the sympathetic divided in the neck; though it ceases to occur, unless the stimulus applied be much stronger, when the cerebro-spinal nerves distributed to the auricle are divided. Schiff, however, whilst agreeing with Bernard as to the occurrence of an active dilating influence being exerted upon the muscular coats of the vessels, maintains, in opposition to the results of the experiments above related (§ 705), that all the vasomotor nerves of the trunk and extremities originate in the Medulla Oblongata, and, descending through the spinal cord, issue with the anterior roots of the spinal nerves; for he has observed a marked elevation of temperature in the foot and lower part of the leg of animals in which he had divided the anterior roots of the sacral nerves, and in the temperature of the upper part of the leg after section of the anterior roots of the three or four lower dorsal nerves. In the face of these discrepant results, obtained by able experimenters, it is obvious that no general conclusions

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* "Proceedings of the Royal Society," vol. xi. p. 302.

† Ibid. p. 436.

can be drawn as yet respecting the real origin of the sympathetic vaso-motor fibres.

707. It can only be through the Nervous System that the Muscular apparatus of Organic life is acted-upon by states of Mind. Although no exertion of the *Will* can produce any effect upon any part of it, yet there are various organs whose muscular walls are influenced on the one hand by Emotional states, and on the other by the state of Expectant Attention. The Heart sympathizes so much with the emotions, that the language of almost all civilized nations refers to it as the *seat* of the 'feelings' (§ 216); but we have as yet no certain evidence whether this influence is transmitted through the Sympathetic or through the Pneumogastric nerve. The former seems the more probable channel, when we bear in mind that it can be through the Sympathetic alone that those alterations in the diameter of the blood-vessels take-place which give-rise to the *blush* of modesty or shame, or to the pallor which alternates with this in many states of mental agitation.* So, again, the influence of Emotional states is strikingly manifested in the production of the peculiar turgescence of the Erectile tissues (§ 255); and here we have a striking example of the utter powerlessness of the Will, in the well-known fact, that no amount of sexual *desire* will produce erection, if the mind be possessed with any feeling of doubt or apprehension as to the existence of the sexual *ability*. The muscular walls of the Alimentary canal seem frequently to be excited to increased action by agitating emotions; but it may be doubted how far this is a primary effect of the mental state, or how far it is consequent upon the influence of that state upon the Secretions poured into the canal (§ 710).—The influence of the state of *expectant attention*, as of the emotions, is strongly manifested in the case of the Heart; the action of which, as Sir H. Holland has remarked, "is often quickened or otherwise disturbed by the mere centering the consciousness upon it, without any emotion or anxiety. On occasions where its beats are audible, observation will give proof of this, or the physician can very often infer it while feeling the pulse; and where there is liability to irregular pulsation, such action is seemingly brought-on, or increased, by the effort of attention, even though no obvious emotion be present."† There can be no doubt that the movements of the lower part of the Alimentary Canal are capable of being affected in a similar manner; since we may frequently trace the rapid descent of the fæcal mass into the rectum, when we expect to be shortly able to discharge it; and it is in great part in this mode, that *habit* operates in producing a readiness for defecation at particular times, and that bread-pills and other supposititious purgatives unload the bowels."‡

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* The pallor of extreme fear or terror is probably due rather to a state tending to Syncope, arising from a partial failure of the Heart's action.

† "Chapters on Mental Physiology," p. 16.

‡ The Author may mention the two following cases, which have fallen within his own knowledge, as curious illustrations of the influence of mental states upon the movements of the alimentary canal.—The first of these occurred in the person of a literary man, of a somewhat hypochondriacal temperament, who had been troubled with continued costiveness, for which he had been accustomed to take an aperient pill daily. Finding that this ceased to have its usual effect, and being fearful of increasing his regular dose, he applied for advice to a practitioner, who, having had former experience of what Mental agency alone would do, determined to try its effect in this instance. Seating his patient

708. Evidence[*] derived from various sources has been collected by M. Brown-Séquard, tending to show that reflex actions may take place not only through the Cerebro-spinal nerves, but also through the cords and ganglia of the Sympathetic system; and he has adduced many instances of irritation applied to parts supplied by these nerves being propagated to great distances, and ultimately exerting an influence either on *striated* or *nonstriated muscular tissue*, producing spasmodic or persistent contraction, or atrophy; or upon *nervous tissue*, producing paralysis, anæsthesia, or hyperæsthesia; or upon *glandular structures*, causing increased or altered secretion; or, lastly, upon the *substance of the tissue itself*, effecting a modification in the nutritive functions, as indicated by alterations in its structure and changes in its temperature and vital properties. The effects of irritation of the peripheral branches of the Sympathetic nerves upon the voluntary muscles are often witnessed in the Strabismus and epileptiform seizures, which are frequently occasioned by the presence of worms in the intestinal canal; whilst the influence exerted upon the unstriped form of muscular tissue may be seen in the irregular contractions of the intestines, accompanied by colic and diarrhœa, which are produced by the passage of unwholesome substances through the digestive tract. The influence of such irritation in producing reflex paralysis, or some other symptom indicative of disorder of the nervous system, may be proved by reference to many recorded cases of paraplegia induced by disease of the bladder, prostate, or kidney, and to a similar effect produced in children by irritation of the dental nerves or of the bowels. Examples of the reflex action of the nervous system upon glands through fibres belonging to the *Cerebro-spinal* system have been already mentioned in the description of the hepatic (§ 381), salivary (§ 80), and lachrymal (§ 710) glands; and there are various instances on record of a similar effect being produced through the agency of the *Sympathetic* system, as in the case of division of the œsophagus, described by Dr. Gairdner, in which a quantity of saliva, amounting to from four to six ounces, was secreted, during the injection of a meal of broth into the stomach; and in the instance observed by M. Brown-Séquard of the secretion of gastric juice following injections of warm water into the rectum of a dog in which a gastric fistula had been formed. Various examples of disturbance of vasomotor nerves, apparently of a similarly-reflex character, supervening in the course of

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before him, with the abdomen uncovered, he desired him to fix his attention intently upon his abdominal sensations, and assured him that in a short time he was quite certain that he would begin to feel a movement in his bowels, which would end in a copious evacuation. He himself did nothing but look steadily at his patient, with an air of great determination and confidence, and point his finger at the abdomen, moving it along the arch of the colon, and (as it were) in the course of the convolutions of the small intestines, so as to aid the patient in fixing his attention upon them. In a short time the expected movements were felt, and a copious evacuation soon followed; and for some time afterwards, the bowels continued to act freely without medicine.—In the other case, a Lecturer at a public Institution was seized with a strong impulse to defecation during his lecture; and was greatly inconvenienced by the effort necessary to restrain it. Before every subsequent lecture in the same place, the same impulse returned upon him, notwithstanding that he might have previously unloaded his bowels elsewhere. In this case, there was obviously a state of apprehension combined with the simple anticipation; but the influence of the latter is shown by the fact, that in no other place did this individual experience the impulse in question under the like circumstances.

chronic diseases, have been collected by M. Leudet;[*] who especially refers to changes in the sensibility, motion, and temperature of different parts of the body,[†] as for instance, flying muscular pains, formication, numbness, "dying out" of one or more fingers, and paralysis occurring in phthisis, scurvy, and Saturnine poisoning.

709. The influence of the Nervous System upon those formative processes which constitute the function of Nutrition, is less evident than it is upon the Secretory operations; and the nature of this influence is rather to be inferred from the results of its withdrawal, than to be demonstrated in any more direct manner. These results are chiefly to be seen in the altered nutrition of parts exposed to external impressions, as the integuments generally, but particularly those of the extremities; and they may be generally expressed by the statement, that the withdrawal of nervous influence from a part renders it less able to withstand the destructive influence of physical agencies. It has been clearly shown, however, by the careful experiments of M. Brown-Séquard, that a great part of the injurious effects which may be observed to follow injuries of the nerves of the extremities, experimentally inflicted, are traceable to want of power on the part of the animal (consequent upon the paralyzed state of the limbs) to withdraw them from irritating impressions; and must not be attributed to any deterioration of the formative operations, directly resulting from the withdrawal of nervous agency. The following case, however, which is given by Mr. Paget[‡] on the authority of Mr. Hilton, seems more unequivocally to establish this connection:—"A man was at Guy's Hospital, several years ago, who, in consequence of a fracture at the lower end of the radius, repaired by an excessive quantity of new bone, suffered compression of the median nerve. He had ulceration of the thumb, and of the fore and middle fingers, which had resisted various treatment, and was cured only by so binding the wrist, that the parts on the palmar aspect being relaxed, the pressure on the nerve was removed. So long as this was done, the ulcers became and remained well; but as soon as the man was allowed to use his hand, the pressure on the nerves was removed, and the ulceration in the parts supplied by it returned." Mr. Paget[§] also mentions the following curious case:—"A lady who is subject to attacks of what are called nervous headaches, always finds next morning that some patches of her hair are white, as if powdered with starch. The change is effected in a night; and in a few days after, the hairs gradually regain their dark brownish colour."—That such effects are rather to be attributed to the loss or perversion of the influence of the Sympathetic system, than to that of the Cerebro-spinal, would appear from the fact noticed by Magendie and Longet, that destructive inflammation of the eye ensues more quickly after division of the Fifth pair *in front* of the Gasserian ganglion, than when the division is made through the roots of the nerve, between that ganglion and the brain; the Sympathetic filaments which exist largely in this nerve, being interrupted in their course to the tissues in the former case, but not in the latter. So Dr. Axmann found, that when the Spinal nerves of Frogs were divided *in front* of their Prevertebral ganglia, the nutrition of the parts supplied by them was much

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[*] "Archives Générales de Médecine," 1864, vol. i. p. 150.

[†] See also Walshe, "Treatise on Diseases of the Lungs," 1860, p. 458.

[‡] "Lectures on Surgical Pathology," vol. i. p. 43.

[§] Op. cit. p. 46.

more injuriously affected, than it was when the section was made between these ganglia and the Spinal Cord. And this inference is further supported by the general result of observation, that atrophy of parts supplied by the Spinal nerves is much greater when the sensory (gangliated) as well as the motor roots are involved, than when the latter alone are paralyzed.[*]—In considering these and similar cases, however, caution is requisite to avoid confounding the effects of irritation producing reflex action of an abnormal character, with those of absence of action of the nervous system in any part, owing to disease or injury of the nervous trunks. Simple absence of action usually produces but little effect. Irritation, on the contrary, especially in nerves distributed to the skin, is often followed by cutaneous eruptions, as Herpes, Pemphigus, &c.[†] An interesting case of the results of absence of action has been recorded by Mr. Jon. Hutchinson,[‡] where a deep cut of the wrist was received, which was followed by swelling and blistering of the fore-finger, the temperature of which was lowered to 10° Fahr. below that of the thumb (76° : 86°). In this instance there was complete insensibility of the last and part of the second phalanx, the latter symptoms enduring for two years. Again in the inflammation just alluded-to as occurring in the eye after section of the Fifth nerve, the mere act of division, if this be accomplished by a clean cut, appears to have but little effect when the eye is carefully protected; but the nutrition of the part is so far altered, that exposure to sources of irritation, which in the sound eye are inoperative, are now, owing to diminished power of resistance, sufficient to occasion acute inflammation; [§] and the same explanation may probably be offered for the changes occurring in the lungs after section of Pneumogastrics (§ 281).

710. The influence of particular conditions of the Mind, in exciting, suspending, or modifying various Secretions, is a matter of daily experience. The *Lachrymal* secretion, for example, which is continually being formed to a small extent for the purpose of bathing the surface of the eye, is poured-out in great abundance under the moderate excitement of the emotions, either of joy, tenderness, or grief. It is checked, however, by violent emotions; hence in intense grief, the tears do not flow; and it is a well-known indication of moderated sorrow when the gush takes place, this very act affording a further relief. The flow of *Saliva*, again, is stimulated by the sight, the smell, the taste, or even by the *thought* of food, especially of such as is of a savoury character. On the other hand, violent emotion may suspend the salivary secretion; as is shown by the well-known test, often resorted-to in India, for the discovery of a thief amongst the servants of a family,—that of compelling all the parties to hold a certain quantity of rice in the mouth during a few minutes,—the offender being generally distinguished by the comparative dryness of his mouthful at the end of the experiment. There is much reason to believe that the secretion of *Gastric* fluid is affected, in the same manner as that of the saliva, by the impressions made by food upon the senses; for it has been ascertained by Bidder and Schmidt[||] that it is copiously

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[*] Paget, Op. cit. p. 48.

[†] See M. Charcot's cases in "Journal de la Physiologie," 1859, vol. ii. p. 108.

[‡] "Med. Times and Gaz.," vol. ii. 1863, p. 197.

[§] See the report of Snellen's researches in Henle and Meissner's "Bericht" for 1857, p. 370; and Büttner in "Zeitschrift f. Rat. Medicin," band xv. p. 254.

[||] Op. cit. p. 35.

effused into the stomachs of dogs that have been kept fasting, when flesh or any other attractive food is placed before them. That the secretion, on the other hand, is entirely suspended by powerful mental emotion, seems almost certain, from the well-known influence which this has in dissipating the appetite for food, and in suspending the digestive process when in active operation. As a cheerful state of feeling, on the other hand, seems to be decidedly favourable to the performance of the digestive function, it probably exerts a beneficial influence, as to both quantity and quality, on the secretion of gastric fluid. Of the influence of mental states on other secretions concerned in the reduction and appropriation of the food (such as the Biliary, Pancreatic, and Intestinal fluids), neither observation nor experiment has as yet afforded any satisfactory information. It is a prevalent, and perhaps not an ill-founded opinion, that melancholy and jealousy have a tendency to increase the quantity, and to vitiate the quality, of the *Biliary* fluid. Perhaps the disorder of the organic functions is more commonly the source of the former emotion than its consequence; but it is certain that the indulgence of these feelings produces a decidedly morbific effect by disordering the digestive processes, and thus reacts upon the nervous system by impairing its healthy nutrition. A copious secretion of *fœtid gas* not unfrequently takes-place in the intestinal canal, under the influence of any disturbing emotion; or the usual *fluid secretions* from its walls are similarly disordered. The tendency to Defecation which is commonly excited under such circumstances, is not, therefore, due simply to the relaxation of the sphincter ani (as commonly supposed); but is partly dependent on the unusually-stimulating character of the fæces themselves. The same may be said of the tendency to Micturition, which is experienced under similar conditions; the change in the character of the *Urine* becoming perceptible enough among many animals, in which it acquires a powerfully-disagreeable odour under the influence of fear, and thus answers the purpose which is effected in others by a peculiar secretion. The *halitus from the Lungs* is sometimes almost instantaneously affected by bad news, so as to produce fœtid breath. The *odoriferous secretion of the Skin*, which is much more powerful in some individuals than others, is increased under the influence of certain mental emotions (as fear or bashfulness), and commonly also by sexual desire. The *Sexual* secretions themselves are strongly influenced by the condition of the mind. When it is frequently and strongly directed towards objects of passion, these secretions are increased in amount, to a degree which may cause them to be a very injurious drain on the powers of the system. On the other hand, the active employment of the mental and bodily powers on other objects, has a tendency to render less active, or even to check altogether, the processes by which they are elaborated.*

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* This is a simple Physiological fact, but of high Moral application. The Author would say to those of his younger readers, who urge the wants of Nature as an excuse for the illicit gratification of the sexual passion, "Try the effects of *close mental application* to some of those ennobling pursuits to which your profession introduces you, in combination with *vigorous bodily exercise* (for the effects of which see § 543), before you assert that the appetite is unrestrainable, and act upon that assertion." Nothing tends so much to increase the desire, as the continual direction of the mind towards the objects of its gratification, especially under the favouring influence of sedentary habits; whilst nothing so effectually represses it, as the determinate exercise of the mental faculties

711. No Secretion so strongly manifests the influence of the Nervous system, and especially of Emotional states, both upon its quantity and its quality, as that of the *Mammary* glands. Although the production of Milk, when once established, continually goes-on in the breasts of a nursing female, yet it is obviously accelerated in the first instance, and augmented afterwards, by the mechanical irritation of the nipple produced by the suction of the infant; and this alone (or in combination with the strong *desire* to furnish milk) has been effectual in producing the secretion in girls and old women, and even in men. Again, in the nursing female the secretion is often suddenly augmented by the *sight* of the infant, or even by the *thought* of him in absence, especially when associated with the idea of suckling; this gives-rise to the sudden rush of blood to the gland, which is known by nurses as the *draught*, and which may probably be attributed to a dilatation of the Mammary arteries, through the instrumentality of their Sympathetic nerves, analogous to that which takes-place in the act of blushing (§ 707).—Although we are continually witnessing indications of the powerful influence of Emotional states upon the qualities of the Mammary secretion, yet it is probable that such influence is not at all peculiar to the milk; and that we only recognize it more readily in this case, because the digestive system of the Infant is a more delicate apparatus for testing it than any which the Chemist can devise; affording proof, by disorder of its function, of changes in the character of the secretion which no examination of its physical properties could detect. The following remarks on this subject are abridged from Sir A. Cooper's valuable work on the Breast:—"The secretion of milk proceeds best in a *tranquil state of mind*, and with a cheerful temper; then the milk is regularly abundant, and agrees well with the child. On the contrary, a *fretful temper* lessens the quantity of milk, makes it thin and serous, and causes it to disturb the child's bowels, producing intestinal fever and much griping. *Fits of anger* produce a very irritating milk, followed by griping in the infant, with green stools. *Grief* has a great influence on lactation, and consequently upon the child. The loss of a near and dear relation, or a change of fortune, will often so much diminish the secretion of milk, as to render adventitious aid necessary for the support of the child. *Anxiety of mind* diminishes the quantity, and alters the quality, of the milk. The reception of a letter which leaves the mind in anxious suspense, lessens the draught, and the breast becomes empty. If the child be ill, and the mother is anxious respecting it, she complains to her medical attendant that she has little milk, and that her infant is griped and has frequent green and frothy motions. *Fear* has a powerful influence on the secretion

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upon other objects, and the expenditure of nervous energy in other channels.—There seems to be something in the process of training young men for the Medical Profession, which encourages in them a laxity of thought and expression on these matters, that too frequently ends in a laxity of principle and of action. It might have been expected that those who are so continually witnessing the melancholy consequences of the violation of the Divine law in this particular, would be the last to break it themselves; but this is unfortunately very far from being the case. The Author regrets being obliged further to remark, that some works which have issued from the Medical press, contain much that is calculated to excite, rather than to repress, the propensity; and that the advice sometimes given by practitioners to their patients, is immoral as well as unscientific.

of milk. I am informed by a medical man who practises much among the poor, that the apprehension of the brutal conduct of a drunken husband will put a stop for a time to the secretion of milk. When this happens, the breast feels knotted and hard, flaccid from the absence of milk, and that which is secreted is highly irritating; and some time elapses before a healthy secretion returns. *Terror*, which is sudden and great fear, instantly stops this secretion." Of this, two striking instances, in which the secretion, although previously abundant, was completely arrested by this emotion, are detailed by Sir A. Cooper. "Those passions which are generally sources of pleasure, and which, when moderately indulged, are conducive to health, will, when carried to excess, alter, and even entirely check, the secretion of milk."

712. There is even evidence that the Mammary secretion may acquire an actually *poisonous* character, under the influence of violent mental excitement; for certain phenomena which might otherwise be regarded in no other light than as simple coincidences, appear to justify this inference, when interpreted by the less striking but equally decisive facts already mentioned. "A carpenter fell into a quarrel with a soldier billeted in his house, and was set-upon by the latter with his drawn sword. The wife of the carpenter at first trembled from fear and terror, and then suddenly threw herself furiously between the combatants, wrested the sword from the soldier's hand, broke it in pieces, and threw it away. During the tumult, some neighbours came-in and separated the men. While in this state of strong excitement, the mother took-up her child from the cradle, where it lay playing, and in the most perfect health, never having had a moment's illness; she gave it the breast, and in so doing sealed its fate. In a few minutes the infant left-off sucking, became restless, panted, and sank dead upon its mother's bosom. The physician who was instantly called-in, found the child lying in the cradle, as if asleep, and with its features undisturbed; but all his resources were fruitless. It was irrecoverably gone."* In this interesting case, the milk must have undergone a change which gave it a powerful sedative action upon the susceptible nervous system of the infant.—The following, which occurred within the Author's own knowledge, is perhaps equally valuable to the Physiologist, as an example of the similarly-fatal influence of undue emotion of a different character; and both should serve as a salutary warning to mothers, not to indulge either in the exciting or in the depressing passions. A lady having several children, of which none had manifested any particular tendency to cerebral disease, and of which the youngest was a healthy infant a few months old, heard of the death (from

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* Dr. Von Ammon, in his treatise "Die ersten Mutterpflichten und die erste Kindespflege," quoted in Dr. A. Combe's excellent little work on "The Management of Infancy."—Similar facts are recorded by other writers. Mr. Wardrop mentions ("Lancet," No. 516), that having removed a small tumour from behind the ear of a mother, all went well, until she fell into a violent passion; and the child, being suckled soon afterwards, died in convulsions. He was sent-for hastily to see another child in convulsions, after taking the breast of a nurse who had just been severely reprimanded; and he was informed by Sir Richard Croft, that he had seen many similar instances. Three others are recorded by Burdach ("Physiologie," § 522); in one of them, the infant was seized with convulsions on the right side and hemiplegia on the left, on sucking immediately after its mother had met with some distressing occurrence. Another case was that of a puppy, which was seized with epileptic convulsions, on sucking its mother after a fit of rage.

acute hydrocephalus) of the infant child of a friend residing at a distance, with whom she had been on terms of close intimacy, and whose family had increased almost contemporaneously with her own. The circumstance naturally made a strong impression on her mind; and she dwelt upon it the more, perhaps, as she happened, at that period, to be separated from the rest of her family, and to be much alone with her babe. One morning, shortly after having nursed it, she laid the infant in its cradle, asleep and apparently in perfect health; her attention was shortly attracted to it by a noise; and on going to the cradle, she found her infant in a convulsion, which lasted a few moments and then left it dead. Now, although the influence of the mental emotion is less unequivocally displayed in this case than in the last, it can scarcely be a matter of doubt; since it is natural that no feeling should be stronger in the mother's mind under such circumstances, than the fear that her own beloved child should be taken from her, as that of her friend had been; and it is probable that she had been particularly dwelling on it, at the time of nursing the infant on that morning.—Another instance, in which the maternal influence was less certain, but in which it was not improbably the immediate cause of the fatal termination, occurred in a family nearly related to the Author's. The mother had lost several children in early infancy, from a convulsive disorder; one infant, however, survived the usually-fatal period; but whilst nursing him one morning, she had been strongly dwelling on the fear of losing him also, although he appeared a very healthy child. In a few minutes after the infant had been transferred into the arms of the nurse, and whilst she was urging her mistress to take a more cheerful view, directing her attention to his thriving appearance, he was seized with a convulsion-fit, and died almost instantly. Now although there was here unquestionably a predisposing cause, of which there is no evidence in the other cases, it can scarcely be doubted that the *exciting* cause of the fatal disorder is to be referred to the mother's anxiety. This case offers a valuable suggestion,—which, indeed, would be afforded by other considerations,—that an infant, under such circumstances, should not be nursed by its mother, but by another woman of placid temperament, who has reared healthy children of her own.

713. There is abundant evidence that a *sudden* and *violent* excitement of some depressing Emotion, especially Terror, may produce a severe and even a fatal disturbance of the Organic functions; with general symptoms (as Guislain* has remarked) so strongly resembling those of sedative Poisoning, as to make it highly probable that the *blood* is *directly* affected by the Emotional state, through Nervous agency; and, in fact, the emotional alteration of various secretions, just alluded-to (§§ 710, 712), seems much more probably attributable to some such affection of the blood, than to a primary disturbance of the secreting process itself. Although there can be no doubt that the *habitual* state of the Emotional sensibility has an important influence upon the general activity and perfection of the Nutritive processes,—as is shown by the well-nourished appearance usually exhibited by those who are free from mental anxiety as well as from bodily ailment, contrasted with the "lean and hungry look" of those who are a prey to continual disquietude,—yet it is not often that we have the opportunity of observing the production of change

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* "Leçons Orales sur les Phrénopathies," tom. iii. pp. 165–168.

in the nutrition of any specific part, by strong emotional excitement. In the two following cases, the correspondence of the effects to their alleged causes *may* have been only casual; and a much larger collection of facts would be needed to *establish* the rationale here advanced as probable. But so many analogous though less strongly-marked phenomena are presented in the records of medical experience, and the influence of the Emotions upon the products of Secretion is so confirmatory, that there does not seem any reasonable ground for hesitation, in admitting that the same explanation may apply here also. The first of these cases, cited by Guislain (loc. cit.) from Ridard, is that of a woman who, after seeing her daughter violently beaten, was seized with great terror, and suddenly became affected with gangrenous erysipelas of the right breast. But a still more remarkable example of local disorder of nutrition, occasioned by powerful emotion, and determined as to its seat by the intense direction of the attention to a particular part of the body, is narrated by Mr. Carter.* "A lady, who was watching her little child at play, saw a heavy window-sash fall upon its hand, cutting off three of the fingers; and she was so much overcome by fright and distress as to be unable to render it any assistance. A surgeon was speedily obtained, who, having dressed the wounds, turned himself to the mother, whom he found seated, moaning, and complaining of pain in her hand. On examination, three fingers, corresponding to those injured in the child, were discovered to be swollen and inflamed, although they had ailed nothing prior to the accident. In four-and-twenty hours, incisions were made into them, and pus was evacuated; sloughs were afterwards discharged, and the wounds ultimately healed."

714. The influence of the state of *expectant attention*, in modifying the processes of Nutrition and Secretion, is not less remarkable than we have already seen it to be in the production or modification of Muscular movements (§ 707). It seems certain that the simple *direction of the consciousness* to a part, independently of emotional excitement, but with the *expectation* that some change will take-place in its organic activity, is often sufficient to induce such an alteration; and would probably always do so, if the concentration of the attention were sufficient. The most satisfactory exemplification of this principle has been given by the experiments of Mr. Braid, who has succeeded in producing very decided changes in the secretions of particular organs, by the fixation of the attention upon them in the 'hypnotic' state (§ 576). Thus he brought-back an abundant flow of milk to the breast of a female who was leaving-off nursing from defect of milk, and repeated the operation upon the other breast a few days subsequently, after which the supply was abundant for nine months; and in another instance he induced the catamenial flow on several successive occasions, when the usual time of its appearance had passed. It is not requisite, however, to produce the state of Somnambulism for this purpose, if the attention can be sufficiently drawn to the subject in any other mode; thus Mr. Braid† has repeatedly produced the last-named result on a female who possessed considerable

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* "On the Pathology and Treatment of Hysteria," p. 24.

† See his important Memoir on 'Hypnotic Therapeutics,' in "Edinb. Monthly Journal," July, 1853.—Of the reality of this last result, the Author has had an opportunity, through Mr. Braid's kindness, of personally satisfying himself.

power of mental concentration, by inducing her to fix her thoughts upon it for ten or fifteen minutes, so as to bring-on a state of Abstraction.—Now the effects which are producible by this *voluntary* or determinate direction of the consciousness to the result, are doubtless no less producible by that *involuntary* fixation of the attention upon it, which is consequent upon the eager expectation of benefit from some curative method in which implicit confidence is placed. It is to such a state that we may fairly attribute most, if not all, the cures, which have been worked through what is popularly termed the 'imagination.' The cures are real facts, however they may be explained; and there is scarcely a malady in which amendment has not been produced, not merely in the estimation of the patient, but in the more trustworthy opinion of medical observers, by practices which can have had no other effect than to *direct the attention* of the sufferer to the part, and to keep alive his *confident expectation* of the cure. The 'charming-away' of warts by spells of the most vulgar kind, the imposition of royal hands for the cure of the 'evil,' the pawings and strokings of Valentine Greatrakes, the manipulations practised with the 'metallic tractors,'* the invocations of Prince Hohenlohe, *et hoc genus omne*,—not omitting the globulistic administrations of the Infinitesimal doctors, and the manipulations of the Mesmerists, of our own times,—have all worked to the same end, and have all been alike successful. It is unquestionable that, in all such cases, the benefit derived is in direct proportion to the *faith* of the sufferer in the means employed; and thus we see that a couple of bread pills will produce copious purgation, and a dose of *red* poppy syrup will serve as a powerful narcotic, if the patient have entertained a sufficiently-confident expectation of such results.†

715. This state of confident expectation, however, may operate for evil, no less than for good. A fixed belief that a mortal disease had seized upon the frame, or that a particular operation or system of treatment would prove unsuccessful, has been in numerous instances (there is no reason to doubt) the direct cause of a fatal result. Thus M. Ridard relates the case of a man, thirty years of age, who was affected with stone in the bladder, and who saw a patient die by his side, after being operated-upon for the same complaint. The man's imagination became excited; his thoughts were constantly fixed upon the operation which he himself expected to undergo, and upon the probable death that would follow; and, in fact, without any operation at all, he died at the end of a month, affected with gangrene both of penis and scrotum. Hence also it is, that the morbid feelings of the Hypochondriac, who is constantly directing his attention to his own fancied ailments, tend to induce real disorder in the action of the organs which are supposed to be affected.—In the same category, too, may be placed those instances (to which alone any value is to be attached), wherein *a strong and persistent impression*

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* Dr. Haygarth of Bath (in conjunction with Mr. Richard Smith of Bristol) tested the value of 'Perkins's metallic tractors,' by substituting two pieces of wood painted in imitation of them, or even a pair of tenpenny nails disguised with sealing-wax, or a couple of slate-pencils; which they found to possess all the virtues that were claimed for the real instruments.

† A remarkable and thoroughly well-attested case of the cure of a fistula lachrymalis which had advanced so far as to involve disease of the bones of the nose, is recorded in the "History of the Portroyalists."

upon the mind of a Mother, has appeared to produce a corresponding effect upon the development of the *fœtus in utero*. In this case, the effect (if admitted to be really exerted) must be produced upon the maternal *blood*, and transmitted through it to the fœtus; since there is no nervous communication between the parent and the offspring. There is no difficulty, however, in understanding how this may occur, after what has been already stated (§ 199) of the influence of minute alterations in the Blood in determining local alterations of nutrition.

CHAPTER XVI.

OF GENERATION.

1. *General Character of the Function.*

716. Having now passed in review the various operations which are concerned in maintaining the life of the *individual*, we have next to proceed to those which are destined to the perpetuation of the *race*, by the production of successive generations of similar beings. Among Plants, and the lower tribes of Animals, a multiplication of independent beings takes-place without any sexual process whatever, by a process of *gemmation* or 'budding' from the parent-stock; these 'buds,' at first entirely nourished by it, gradually become less and less dependent upon it, and at last detach themselves and maintain a separate existence. Now this process may be regarded as essentially the same with that of the multiplication of cells by *subdivision*, which is one of the most ordinary operations of growth and development; and it is peculiar in nothing else than this,—that the newly-formed structure, instead of remaining as a constituent and dependent part of the parental fabric, is capable of living independently of it, and of thus existing as a distinct individual when spontaneously or artificially detached. Among the higher tribes of Animals, as in Man, this mode of reproduction, which is merely a multiplication of the individual, and not a real Generative process, does not present itself, at least in the adult state; for in no instance do we find that a part of the body separated from the rest can develope the organs which are necessary for the sustenance of its existence; and the power which the organism possesses, of regenerating parts which it has lost by disease or accident, is restrained within very narrow limits (§ 343). But there is good ground to believe, that such a multiplication by subdivision *may* take place at that earliest period of embryonic life, at which the germ is nothing else than a mass of cells, wherein no distinction of parts has as yet manifested itself; and that the production of two complete individuals, held-together only by a connecting band, may arise from some cause which determines the subdivision of the germinal mass, at the period when its grade of development corresponds with that of the Hydra or Planaria (§ 340). And this view of the case is confirmed by the facts already stated (§ 343) in regard to the higher degree of the regenerating power during embryonic life, infancy, and childhood, as

compared with that which remains after the development of the fabric has been completed.

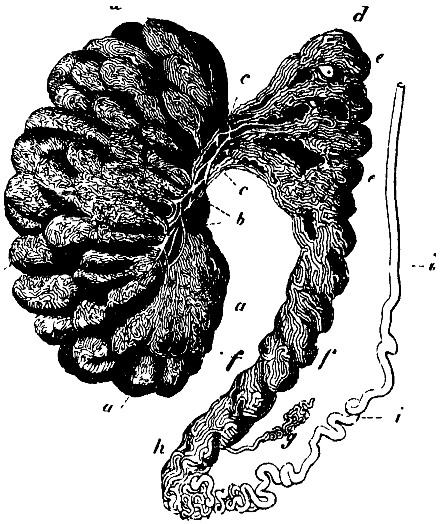
717. The proper act of Generation in Man, as in the Animal and Vegetable Kingdoms generally (see PRINC. OF COMP. PHYS., Chap. XI.), uniformly involves the union of the contents of two peculiar cells, which may be designated as the 'sperm-cell,' and the 'germ-cell;' and, as in all higher Animals, the 'sperm-cell' developes in its interior a self-moving *spermatozoon;* whilst the 'germ-cell' (germinal vesicle) whose contents are fertilized by the spermatozoon, is imbedded in a mass of *yolk* destined for the early nutrition of the embryo thence originating; so that this embryo, if supplied with the requisite warmth, as well as drawing into itself the aliment stored-up for it, gradually evolves itself into the likeness of its parent. There is a great difference, however, among the different tribes of Animals, as to the degree of assistance thus afforded to the embryo; the general rule being, that the higher the form which the embryo is ultimately to attain, the longer is it supported by its parent. Hence we find the embryos of most Invertebrated animals coming-forth from the egg in a condition very unlike their perfect type, and only acquiring this after a long succession of subsequent alterations, which frequently involve a complete change of form, or *metamorphosis.* In Fishes, however, the embryo, though far from having completed its embryonic development at the time of its emersion from the egg, does not differ so widely from the adult type. In Birds, there is a provision for a much more advanced development; the store of nutritious matter, or 'yolk,' being so large as to allow the whole series of changes requisite for the formation of the complete chick to take-place before it leaves the egg. In the Mammalia, on the contrary, the quantity of yolk contained in the ovum is very small, but the embryo is only dependent upon it for the materials of its increase during the earliest stages of its evolution; for it speedily forms a special connection with the parent-structure, by means of which it is enabled to receive a continual supply of newly-prepared aliment, so as to be supported at the expense of this until far advanced in its development. Some approaches to this arrangement are met-with among certain of the lower animals, but it is only in the higher Mammalia that it is completely carried-out; and it is only in this class, too, that we find a supplemental provision for the nutrition of the offspring after it has come forth into the world. A considerable difference in the ova of different animals further exists, as was first shown by Reichert, in the circumstance that in some the whole yolk is applied directly to the formation of the embryo; whilst in others, only a portion is so employed, the remainder being as it were a store of food which is gradually taken-up in the process of development. The former kind of egg consists, therefore, altogether of germ-yolk; the latter of a small germ-yolk, and a large food-yolk. The former has been called 'holoblastic,' the latter 'meroblastic.' The former is found in Man and Mammals, Batrachians, Cyclostome Fishes, the lower Crustacea, Arachnida and Mollusca, Annelids, Worms and Radiate animals; the latter in Birds, Amphibia, Fishes, Cephalopods, and the higher groups of Crustacea and Arachnida. In many of the lower tribes of animals, the fertilization of the ova is accomplished without any sexual congress; the spermatic fluid effused by the male, coming into direct contact with the ova pre-

viously deposited by the female; but in all the higher tribes, as in Man, the spermatic fluid is conveyed into the oviducts of the female, so as to impregnate the ovum shortly after it has quitted the ovarium, or even before its final escape from it.

2. *Action of the Male.*

718. The Spermatic fluid of the Male is secreted by glandular organs, known as *Testes*. Each of these consists of several lobules, which are separated from each other by processes of the Tunica Albuginea that pass down between them, and also by an extremely delicate membrane (described by Sir A. Cooper under the name of Tunica Vasculosa) consisting of minute ramifications of the spermatic blood-vessels united by areolar tissue. Each lobule (Fig. 153, *a a*) is composed of a mass of convoluted *tubuli seminiferi*, throughout which blood-vessels are minutely distributed. The lobules differ greatly in size, some containing one, and others many of the tubuli; the total number of the lobules is estimated at about 450 in each testis, and that of the tubuli at 840. The walls of the tubuli are firmer than those of similar gland-canals elsewhere; for outside the basement-membrane on which the epithelium rests, they have a tolerably-firm but extensible envelope, composed of an indistinctly-fibrous connective tissue with longitudinal nuclei. Their convolutions are so arranged that each lobule forms a sort of cone, the apex of which is directed towards the *rete testis* (*b*); and when they have reached to within a line or two of this, they cease to be convoluted, several unite together into tubes of larger diameter, and these enter the rete testis under the name of *tubuli recti*. The mode in which the tubuli terminate at the large end of the lobule has not been clearly made-out, owing partly to the number of their anastomoses; it is probably either by cæcal endings, or by loops. The diameter of the tubuli is for the most part very uniform; in the natural condition they seem to vary from about the 1-195th to the 1-170th of an inch; but when injected with mercury, they are distended to a size nearly double the smaller of these dimensions.

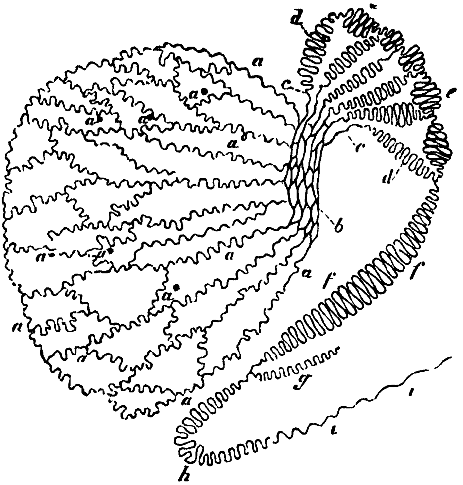
FIG. 153.



Human Testis, injected with mercury as completely as possible:—*a*, *a*, lobules formed of seminiferous tubes; *b*, rete testis; *c*, vasa efferentia; *d*, flexures of the efferent vessels passing into the head, *e*, *e*, of the epididymis; *f*, body of the epididymis; *g*, appendix; *h*, cauda; *i*, vas deferens.

—The *rete testis* (*b*) consists of from seven to thirteen vessels, which run in a waving course, anastomose with each other, and again divide, being all connected together. The *vasa efferentia* (*c*), which pass to the head of the epididymis, are at first straight, but soon become convoluted (*d*), each forming a sort of cone, of which the apex is directed towards the rete testis, the base to the head of the epididymis (*e*). The number of these is stated to vary from nine to thirty; and their length to be about eight inches. The *epididymis* itself (*f*) consists of a very convoluted canal, the length of which is about twenty-one feet. Into its lower extremity, that is, the angle which it makes where it terminates in the vas deferens, is poured the secretion of the *vasculum aberrans* or appendix (*g*); which seems like a testis in miniature, closely resembling a single lobule in its structure. Its special function is unknown.

FIG. 154.



Plan of the structure of the *Testis* and *Epididymis*:—*a*, *a*, seminiferous tubes; *a**, *a**, their anastomoses; the other references as in the last figure.

719. The fluid secreted by the Testis is mingled, during or previously to its emission, with fluid secreted by the Vesiculæ Seminales, the Prostate, Cowper's glands, &c.; and it cannot, therefore, be obtained pure, but by drawing it from the testicle itself. No accurate analysis has been made of it in the Human subject; but Kölliker* has made the following analyses of it in the Bull and Stallion:—

	Bull.	Stallion.
Water	820·60	819·40
Solid residue	179·40	180·60
Spermatin and Extractive	153·0	164·49
Fat	21·6	—
Salts	26·37	16·11

and Frerichs,† on examining the contents of the Testes of a Rabbit, a Cock, and a Carp, found pure Semen to be a milky fluid of a mucous consistence, and neutral or slightly-alkaline reaction. The imperfectly-developed Spermatozoa are composed of an albuminous substance, the quantity of which diminishes with their progress towards maturation; so that the perfectly-developed semen contains no albuminous compound. On the other hand, the principal component substance of the mature Spermatozoa is the same with that which is the chief constituent of the

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* v. Gorup-Besanez, 1862, "Phys. Chem.," p. 424.

† Art. 'Semen,' in "Cyclop. of Anat. and Physiol.," vol. iv. p. 506.

Epithelia and of the Horny tissues generally, namely, the 'binoxide of protein' of Mulder. Besides this, the spermatozoa contain about 4 per cent of a butter-like fat, with some phosphorus in an unoxidized state (probably combined with the fat, as in the phosphorized fats of the blood-corpuscles and of nervous matter), and about 5 per cent of phosphate of lime. The spermatozoa evince little tendency to decomposition, and offer considerable resistance to the action of sulphuric, nitric, hydrochloric, and acetic acids, and to the caustic alkalies in the cold. The fluid portion of the secretion is a thin solution of mucus, which, in addition to the animal matter, contains chloride of sodium, and small quantities of alkaline sulphates and phosphates. When allowed to evaporate spontaneously, crystals of ammoniaco-magnesian phosphate are generally formed in abundance. The peculiar odour which the Semen possesses, does not appear to belong to the proper spermatic fluid; but is probably derived from one or other of the secretions with which it is mingled.—The product of the secretion of each Testis is conveyed away by a single *vas deferens* (*i*), which is a cylindrical canal, having, within its fibrous wall, a layer of non-striated muscular fibre, and being lined by a proper mucous membrane. The vas deferens, ascending into the abdominal cavity as a part of the spermatic cord, reaches the fundus of the bladder; and there it comes into proximity with the *Vesicula Seminalis* of its own side, with whose duct it unites to form the *ejaculatory duct* which terminates on the *verumontanum* of the urethra. It has been commonly supposed that the *vesiculæ seminales* stand to the *vasa deferentia* in the same light that the gall-bladder stands to the hepatic duct; namely, as a receptacle into which the seminal fluid may regurgitate, and within which it may accumulate; but (as Hunter was the first to maintain) this is not the case, since the fluid that is found in them is not semen, and but rarely contains even a small admixture of seminal fluid.* Moreover, these organs are not simple vesicles, but have a sacculated glandular character; and their secretion seems to be of a mucous nature. Into the same part of the urethra is discharged the secretion of the *Prostate Gland*, which is poured-forth by a number (15-20) of separate ducts into a depressed fossa on either side; of the nature of this secretion scarcely anything is known; and it can be only surmised that its use, like that of the fluid of the vesiculæ seminales, is to dilute the seminal fluid, and to give it such an increase of bulk that it may be more effectually conveyed within the female passages. It seems probable, indeed, that a certain dilution of the fluid secreted by the testes may be a condition of its power of fecundation; since it has been ascertained by Mr. Newport, that too copious an application of spermatozoa to an ovum is absolutely unfavourable to their action.—That in some way or other both these glandular bodies serve as accessory organs of generation, may be inferred from the fact, that in animals which have only a periodical aptitude for procreation, they undergo an alternate increase and decrease, corresponding with the periodical enlargement and diminution of the testes themselves.

720. The essential peculiarity of the Spermatic fluid, however, consists in the presence of a large number of very minute bodies, the *spermatozoa*, which, from their usually remaining in active motion for some time after

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* See Art. 'Vesiculæ Seminales,' in "Cyclop. of Anat. and Physiol.," vol. iv. p. 1431.

they have quitted the living organism, have been erroneously considered as proper Animalcules. The Human Spermatozoon (of which representations are given in Plate I., Fig. 1) consists of a little oval flattened 'body' between the 1-600th and the 1-800th of a line in length, from which proceeds a long filiform 'tail' gradually tapering to the finest point, of 1-50th or at most 1-40th of a line in length. The whole is perfectly transparent; and nothing that can be termed 'structure' can be satisfactorily distinguished within it. Its movements are principally executed by the tail, which has a kind of vibratile undulating motion; they may continue for many hours after the emission of the fluid; and they are not checked by its admixture with other secretions, such as the urine and the prostatic fluid. Thus, in cases of nocturnal emission, the Spermatozoa may not unfrequently be found actively moving through the urine in the morning; and those contained in the seminal fluid collected from females that have just copulated, are frequently found to live many days. Their presence may be readily detected by an observer familiar with their appearance, and furnished with a Microscope of sufficient power, even when they have long ceased to move, and are broken into fragments; and the Physician and the Medical Jurist will frequently derive much assistance from an examination of this kind. Thus, cases are of no uncommon occurrence, especially among those who have been too much addicted to sexual indulgence, in which seminal emissions take-place unconsciously and frequently, and produce great general derangement of the health; and the true nature of the complaint is obscure, until the fact has been detected by ocular examination. Again, in charges of rape, in which evidence of actual emission is required, a microscopic examination of the stiffened spots left on the linen will seldom fail in obtaining proof if the act have been completed: in such cases, however, we must not expect to meet with more than fragments of Spermatozoa; but these are so unlike anything else that little doubt need be entertained regarding them. It has been proposed to employ the same test in juridical inquiries respecting doubtful cases of death by suspension, seminal emissions being not unfrequent results of this kind of violence; but there are many obvious objections which should prevent much confidence being placed in it.*

721. The mode of evolution of the Spermatozoa, first discovered by Wagner, and more perfectly elucidated by Kölliker, is such as to indicate that these bodies are true products of the formative action of the organs in which they are found, and cannot be ranked in the same category with Animalcules. They are developed in the interior of cells, or 'vesicles of evolution,' such as are visible in the seminal fluid in various stages of production (Plate I., Fig. 2, A, B, C), and have been known under the name of 'seminal granules.' These appear to have been themselves formed within parent-cells, which are probably to be regarded as the epithelial cells of the tubuli seminiferi; containing, like the analogous cells of other glands, the essential elements of the spermatic apparatus. These parent-cells are sometimes observed to contain but a single 'vesicle of evolution,' as shown at D; but more commonly from three to seven are to be seen within them (E). When taken from a body recently dead, and examined without being treated with water or any other agent, they

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* See the Author's Article 'Asphyxia,' in the "Library of Practical Medicine," and the authorities there referred-to.

are quite pellucid, and exhibit a delicate contour with perfectly homogeneous contents; very speedily, however, a sort of coagulation takes-place within them, by which their contents are rendered granular. Each of these 'vesicles of evolution' gives origin to a spermatozoon, and to one only; the earliest stages of its development have not yet been fully made out, since it does not at first exhibit those sharp distinct contours, dependent on its great refractive power, which afterwards distinguish it; but it is seen lying in the interior of the cell as a slight linear shadow, at first partly hidden by the surrounding granules (Fig. 3, B), but afterwards without any such obscuration. When the vesicle is completely matured, it bursts and gives exit to the contained spermatozoon; but it is common for the parent-cells to retain the vesicles of evolution during the development of the spermatozoa within the latter; so that the spermatozoa set-free by the rupture of these are still enveloped by the parent-cell. In this condition they have a tendency to aggregation in bundles; and these bundles are finally liberated by the rupture of the parent-cell, after which the individual spermatozoa separate one from another. The spermatozoa are not normally found free in the tubuli seminiferi; although they may be there so far advanced in development, that the addition of water liberates them by occasioning the rupture of their envelopes. In the rete testis and vasa efferentia, the spermatozoa are very commonly found lying in bundles within the parent-cells, the vesicles of evolution having disappeared; and they are usually set-free completely by the time that they reach the epididymis, though still frequently associated in bundles. The earlier phases are occasionally met-with, however, even in the vas deferens.*

722. That the Spermatozoa are the essential elements of the spermatic fluid, may be reasonably inferred from several considerations. There are some cases in which the 'liquor seminis' is altogether absent, so that they constitute the sole element of the semen; whilst, on the other hand, they are never wanting in the semen of animals capable of procreation; but are absent, or imperfectly developed, in the semen of hybrids, which are nearly or entirely sterile. Moreover, it may be considered as certain that the absolute contact of the spermatozoa with the ovum is requisite for its fecundation; whilst, on the other hand, if the spermatozoa be carefully removed from the liquor seminis by filtration, the latter is entirely destitute of fertilizing power.† Hence the presence of the Liquor Seminis must be considered as merely incidental; and as answering some secondary purpose, either in the development or in the conveyance of the Spermatozoa.

723. The power of procreation does not usually exist in the Human Male before the age of from 14 to 16 years; and it may be considered probable that no Spermatozoa are produced until that period, although a fluid is secreted by the testes. At this epoch, which is ordinarily designated as that of *Puberty*, a considerable change takes-place in the bodily constitution: the sexual organs undergo a much-increased development;

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* For the latest researches on the development, &c. of the Spermatozoa, see the elaborate Article 'Semen,' in the "Cyclop. of Anat. and Physiol.," by Drs. Wagner and Leuckardt, and Prof. Kölliker's "Manual of Microscopic Anatomy," 1860.

† This point was completely established by the researches of Mr. Newport ("Phil. Trans.," 1851), who repeated and confirmed the experimental results previously obtained by Spallanzani and by Prevost and Dumas.

various parts of the surface, especially the chin and the pubes, become covered with hair; the larynx enlarges, and the voice becomes lower in pitch, as well as rougher and more powerful; and new feelings and desires are awakened in the mind. Instances, however, are by no means rare, in which these changes occur at a much earlier period; the full development of the generative organs, with manifestations of the sexual passion, having been observed in children but a few years old. The procreative power may last, if not abused, during a very prolonged period. Undoubted instances of virility at the age of more than 100 years are on record; but in these cases, the general bodily vigour was preserved in a very remarkable degree. The ordinary rule seems to be, that sexual power is not retained by the male to any considerable amount, after the age of 60 or 65 years.

724. To the use of the sexual organs for the continuance of his race, Man is prompted by a powerful instinctive desire (§ 544), which he shares with the lower animals. This Instinct, like the other propensities, is excited by sensations; and these may either originate in the sexual organs themselves, or may be excited through the organs of special sense. Thus in Man it is most powerfully aroused by impressions conveyed through the sight or the touch; but in many other animals, the auditory and olfactory organs communicate impressions which have an equal power; and it is not improbable that, in certain morbidly-excited states of feeling, the same may be the case in ourselves. Localized sensations have also a very powerful effect in exciting sexual desire, as must have been within the experience of almost every one; the fact is most remarkable, however, in cases of Satyriasis, which disease is generally found to be connected with some obvious cause of irritation of the generative system, such as pruritus, active congestion, &c. That some part of the Encephalon is the seat of this as of other instinctive propensities, appears from the considerations formerly adduced; but that the Cerebellum is the part in which this function is specially located, cannot be regarded as by any means sufficiently proved (§§ 540-544). The instinct, when once aroused (even though very obscurely felt), acts upon the mental faculties and moral feelings; and thus becomes the source, though almost unconsciously so to the individual, of the tendency to form that kind of attachment towards one of the opposite sex, which is known as *love*. This tendency cannot be regarded as a simple passion or emotion, since it is the result of the combined operations of the reason, the imagination, and the moral feelings; and it is in this engraftment (so to speak) of the psychical attachment, upon the mere corporeal instinct, that a difference exists between the sexual relations of Man and those of the lower animals. In proportion as the Human being makes the temporary gratification of the mere sexual appetite his chief object, and overlooks the happiness arising from spiritual communion, which is not only purer but more permanent, and of which a renewal may be anticipated in another world,—does he degrade himself to a level with the brutes that perish. Yet how lamentably frequent is this degradation!

725. When, impelled by sexual excitement, the Male seeks intercourse with the Female, the erectile tissue of the genital organs becomes turgid with blood (§ 262), and the surface acquires a much-increased sensibility; this is especially acute in the Glans penis. By the friction of the Glans against the rugous walls of the Vagina, the excitement is increased; and

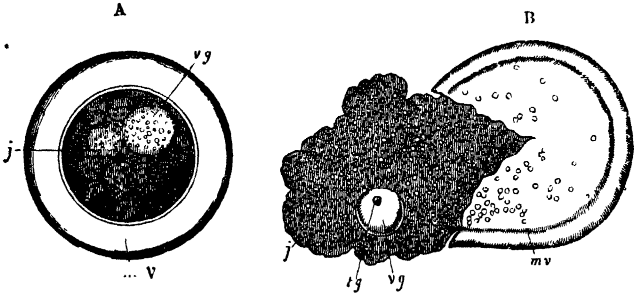
the impression which is thus produced at last becomes so strong, that it calls-forth, through the medium of a ganglionic centre, probably situated in the lower portion of the Spinal Cord, a reflex contraction of the muscular fibres of the Vasa Deferentia, and of the muscles which surround the Vesiculæ Seminales and Prostate gland. These receptacles discharge their contents into the Urethra; from which they are expelled with some degree of force, and with a kind of convulsive action, by its own Compressor muscles; whilst they are prevented from passing back into the bladder, according to Kobelt, by the great distension of the Verumontanum which occurs during the period of erection. Now although the sensations concerned in this act are ordinarily most acutely pleasurable, there appears sufficient evidence that they are by no means essential to its performance; and that the impression which is conveyed to the Spinal Cord *need not* give rise to a sensation, in order to produce the reflex contraction of the Ejaculator muscles (§ 495). The high degree of nervous excitement which the act of coition involves, produces a subsequent depression to a corresponding amount; and the too frequent repetition of it is productive of consequences very injurious to the general health. This is still more the case with the solitary indulgence, which (it is to be feared) is practised by too many youths; for this, substituting an unnatural degree of one kind of excitement for that which is wanting in another, cannot but be still more trying to the bodily powers. The secretion of seminal fluid being, like other secretions, very much under the control of the nervous system, will be increased by the continual direction of the mind towards objects which awaken the sexual propensity (§ 710); and thus, if a frequent discharge be occasioned, whether by natural or unnatural excitement, a much larger quantity will altogether be produced, although the amount emitted at each period will be less, and its due perfection will not be attained, the fluid under such circumstances being found to contain an unduly-large proportion of immature seminal cells. The formation of the secretion seems of itself to be a much greater tax upon the corporeal powers, than might have been supposed *à priori:* and it is a well-known fact, that the highest degree of bodily vigour is inconsistent with more than a very moderate indulgence in sexual intercourse; whilst nothing is more certain to reduce the powers, both of body and mind, than excess in this respect.—These principles, which are of great importance in the regulation of the health, are but expressions of the general law (which prevails equally in the Vegetable and in the Animal kingdom), that the Development of the Individual and the Reproduction of the Species stand in an inverse ratio to each other.

3. *Action of the Female.*

726. The essential part of the Female Generative system, is that in which the Ova are prepared; the other organs are merely accessory, and are not to be found in a large proportion of the Animal kingdom. In many of the lower animals, the Ovarium consists of a loose tissue containing many areolæ, in which the Ova are formed, and from which they escape by the rupture of the cell-walls; in the higher animals, as in the Human female, the substance of the Ovarium is firm and compact, and consists of a nucleated, tough, fibrous, though not distinctly fibrillar, con-

nective tissue, forming what is known as the *stroma*; and the Ova, except when they are approaching maturity, can only be distinguished in the interstices of this, by the aid of a high magnifying power.* The Ovum in all Vertebrated animals is produced within a capsule or bag, the exterior of which is in contact with the stroma of the ovarium; this has been termed, in Mammalia, the *Graafian vesicle*, after the name of its first discoverer; but the more general and appropriate designation of *Ovisac* was given to it by Dr. Barry, who showed that it exists in other classes of Vertebrata.† Between the Ovum and the Ovisac, in Oviparous animals, there is scarcely any interval; but in the Mammalia, a large amount of granular matter (composed of nucleated cells, loosely aggregated together) is present; being especially found adherent to the lining of the ovisac, to which it forms a sort of epithelium, or internal tunic, known as the *membrana granulosa;* whilst it also forms a disk-like investment to the ovum, which is termed the *discus proligerus*. The membrane which incloses the yolk in Mammalia has received, on account

FIG. 155.



Constituent parts of *Mammalian Ovum*:—A, entire; B, ruptured, with the contents escaping;—*m v*, vitelline membrane; *j*, yolk; *v g*, germinal vesicle; *t g*, germinal spot.

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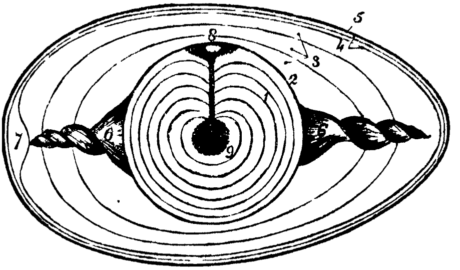
* Several works have lately appeared upon the minute anatomy of the Ovaries, amongst the more important of which are Borsenkow in the "Wurzburger Naturwiss. Zeitschrift," band iv. p. 56; Schrön in the "Zeits. f. Wiss. Zoologie," band xii. heft 3; Quincke in idem, band xii. p. 483; Grohe in "Virchow's Archiv," band xxvi. p. 271; and Pflüger, "Ueber die Eierstocke der Saugethiere und des Menschen," Leipzig, 1863. Pflüger maintains that at an early period tubes may be seen in the ovaries, provided with a membrana propria and an epithelium, within which the eggs develope, and which, by becoming constricted at certain points, form the Graafian follicles. Other observers have been unable to discover these tubes. Borsenkow, however, corroborates Pflüger's observations, having seen them in kittens radiating from the centre towards the periphery of the ovary, and forming chains of follicles. He describes the eggs as proceeding from specially-developed cells contained in these tubes, the egg being consequently, from its very commencement, a cell, and not a free nucleus. The *vesicula germinativa* is the nucleus of this cell, and the contents of the cell are the yolk, the latter being present in the earliest stage, so that there is no surrounding of a nucleus with protoplasm, or of a primitive cell with yolk substance. Quincke has seen eggs with two *vesiculæ germinativæ*, and elongated follicles with two or three eggs, and believes that the Graafian follicles increase by division, and that the whole Graafian follicle is only an enlarged cell, in the interior of which, in consequence of the fission of its nucleus, the egg and the cells of the membrana granulosa develop.

† 'Researches in Embryology,' 1st series, in "Philos. Transact.," 1838.

of its thickness and peculiar transparency, the distinctive appellation of *zona pellucida* (Fig. 155, *m v*).—The yolk or *vitellus* (*j*), which is composed of albumen and oil-particles, with traces of cells, is very small in the Mammalian ovum, its function being limited to the sustenance of the germ during its earliest period of development; and it corresponds rather with that part of the yolk of the egg of the higher Ovipara which has been distinguished as the 'germ-yolk,' in consequence of its direct participation in the formation of the germinal substance, than with that which has been termed the 'food-yolk,' as not being incorporated with the germ, but being destined for its subsequent nutrition by undergoing conversion into blood. Occupying the centre of the vitelline mass, in the immature ovum, is a peculiar cell, very different in its aspect from the surrounding substance, which is termed the *germinal vesicle* (Fig. 155, *v g*); and this has a very distinct nucleus (*t g*), known as the *germinal spot*. This cell must be considered as the essential part of the ovum, and as homologous with the 'germ-cell' or 'embryonal vesicle' of the Vegetable ovule.—The Egg of the Fowl, as it escapes from the ovary, consists of the food-yolk (1, Fig. 156) and the germ-yolk (8 and 9), enclosed in a thin vitelline membrane (2). The germ-yolk appears on the surface of the food-yolk as a small yellowish-white disk, termed the *Cicatricula* (8), in the centre of which the germinal vesicle and germinal spot may sometimes be seen; from the deep surface of the cicatricula a prolongation of the germ-yolk to near the centre of the food-yolk may be traced, forming at this part the *Latebra* (9). The food-yolk (1), of very large size, presents concentric markings, or *halones*, indicating the mode of its formation. As the egg descends the oviduct (the left one being alone developed in the Bird), a remarkable coating of firm albumen is deposited around it, which by the rotation of the egg becomes twisted in opposite directions at the two poles. These portions of albumen are termed the *Chalazæ* (6), and it is by the slight elasticity which they possess that the vitellus is subsequently enabled to float in the surrounding albumen with the cicatricula uppermost; and consequently, whilst closely approximated to the warm body of the mother, freely exposed to light and air. Around the chalazæ successive layers of glairy albumen (3) are deposited, which are finally enclosed by three layers of membrane (4 and 5), the last of which, near the outlet, undergoes calcification in a special secreting segment or chamber of the oviduct. In making a comparison between the egg of the Bird and that of the Mammal, two views may be

FIG. 156.



Sectional view of *Fowl's Egg*:—1, yellow yolk composed of successive layers; 2, vitelline membrane; 3, layers of albumen; 4, two principal layers of the lining membrane of the shell; 5, calcareous shell; 6, chalazæ; 7, air-space between the two layers of the shell; 8, cicatricula, with its nucleus, beneath which is seen the canal leading down to the white yolk cavity or latebra, 9.—(Slightly altered from Allen Thomson).

entertained. On the one hand, Meckel, with whom Allen Thomson* in the main agrees, considers that the white, 'germ' or primitive yolk of the Bird's egg, consisting of the germinal vesicle, granular yolk, and a limitary membrane, or zona pellucida, is the analogue of the whole ovum of Mammals; in which case we may look upon the yellow yolk of the Bird and scaly Reptiles as analogous to the granular cells of the Graafian vesicle and tunica granulosa of the Mammal, the albumen ovi to the uterine secretion, and the calcareous shell to the decidual mucous membrane of the uterus. Kölliker, Hoyer, and Samter, on the other hand, deny the existence at any period of the above-mentioned limitary membrane, or zona pellucida, of the white yolk; and with this the whole case falls to the ground, and we must adopt the other view, that, namely, notwithstanding its large size and complex formation, the entire egg of the Bird corresponds to the entire egg of the Mammal.

727. The Human Ovum is extremely minute; not measuring above 1-120th of an inch in diameter, and being sometimes no more than half that size. The diameter of the germinal vesicle of the Human ovum has not yet been ascertained, owing to the difficulty of isolating it from the yolk; in the ovum of the Rabbit, it is about 1-720th and in the Guinea Pig about 1-1800th of an inch; and that of the germinal spot, in the Mammalia generally, is from 1-3600th to 1-2400th of an inch.

728. It appears, from the researches of Valentin and Bischoff, that in Mammalia the Graafian vesicle, or Ovisac, is formed previously to the Ovum, which is subsequently developed in its interior; and on this view it would seem that we may regard it as a *vesicle of evolution* for the ovum, in the same way that the gland-cells of the testis act as vesicles of evolution for the spermatozoa. But Baer, Barry, and Allen Thomson† maintain that small germ-vesicles may be sometimes detected (in Birds at least), in the stroma of the ovary uncovered by a Graafian follicle or capsule. It is certain that the development of ovisacs commences at a very early period of life; in the ovaries of some animals, they can be detected almost as soon as these organs are themselves evolved; and in all, they show themselves soon after birth. In Plate I., Fig. 4, is represented the condition of the Graafian vesicles in various stages of development, as they are seen imbedded in the fibrous stroma of the ovarium, in a thin slice from the ovary of a sow three weeks old; by which time the germinal vesicle, which is the first part of the ovum that makes its appearance, has been developed in their interior. The germinal vesicle, which distinctly shows the germinal spot, is surrounded by an assemblage of granules, which gives the first indication of a yolk; and around these, the zona pellucida appears to be subsequently developed. The ovum at first occupies the centre of the Graafian vesicle, but it subsequently removes to its periphery; and, when the contents of the ovisac are undergoing maturation, prior to their escape, the ovum is always found on the side of it nearest to the surface of the ovary. The proper Ovisac, whose wall is formed of a non-vascular membrane, is surrounded by a vascular layer, which is formed by a condensation of the ordinary stroma of the ovarium; it is this which is usually described as the outer layer of the Graafian vesicle.

729. A continual change seems to be taking-place in the contents of

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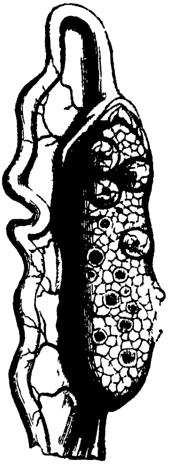
* "Cyclop. of Anat. and Physiol.," Supplement, 1859, p. 77.

† Ibid. p. 76.

the Ovarium during the greater part of life; certain of the Ovisacs or Graafian vesicles, and their contents, successively arriving at maturity, whilst others degenerate and die. According to the valuable inquiries of Dr. Ritchie,* it appears that even during the period of childhood, there is a continual rupture of ovisacs and discharge of ova, at the surface of the ovarium. The Ovaria are studded with numerous minute copper-coloured maculæ, and their surface presents delicate vesicular elevations, which are occasioned by the most matured ovisacs; the dehiscence of these takes-place by minute punctiform openings in the peritoneal coat, and no cicatrix is left. At the period of puberty, the stroma of the ovarium is crowded with ovisacs; which are still so minute, that in the Ox (according to Dr. Barry's computation) a cubic inch would contain 200 *millions* of them. The greatest advance is seen in those which are situated nearest the surface of the Ovarium; and in such, the Graafian vesicle, with its two coats, may be distinctly traced. In those animals whose aptitude for conception is periodical, the development of the ova to such a degree that they become prepared for fecundation, is periodical also. This development is made evident, when the parts are examined in an animal which is 'in heat,' by the projection of the Graafian vesicles from the surface (Fig. 157); and it consists not merely in an increase of size, but in certain internal changes presently to be described (§ 734).

FIG. 157.



Ovarium of the Rabbit, at the period of Heat; showing various stages of the extrusion of ova.

730. In the Human female, the period of *Puberty*, or commencing aptitude for procreation, is usually between the 13th and 16th years; it is generally thought to be somewhat earlier in warm climates than in cold,† and in densely-populated manufacturing towns than in thinly-peopled agricultural districts. The mental and bodily habits of the individual have also considerable influence upon the time of its occur-

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[*] "London Medical Gazette," 1844.

[†] It has been stated, by almost all Physiological writers, that women (like fruits) reach maturity, and that menstruation commences, much earlier in hot climates, particularly between the tropics, than in temperate and very cold countries. From many elaborate and interesting papers which have been published within a few years, however, especially from those of Mr. Roberton of Manchester (recently collected in his "Essays on Menstruation, and on Practical Midwifery," 1851), it would seem that the natural period of puberty in temperate climates occurs in a much more extended range of ages, and is much more equally distributed through that range, than others have alleged; and that, in other countries, the supposed parallel between plants and fruits does not hold good. The fact seems to be, that this, like other *periodic* phenomena of warm-blooded animals, is but little influenced by external temperature, simply because the rate of growth and development, of which these phenomena are the exponents, is determined by the temperature of the body itself, not by that of the surrounding medium. Still it is quite possible that external warmth may have a slight influence in determining early puberty; since, as already shown, it tends to maintain a somewhat higher degree of bodily heat (§ 405). According to Szukitz, the average age at which the catamenia appear amongst German women is 15¼ years; according to Brierre de Boismont, it occurs a year earlier in Parisian girls. See Henle and Meissner's "Bericht," 1857, p. 606.

rence; girls brought-up in the midst of luxury or sensual indulgence, undergoing this change earlier than those reared in hardihood and self-denial. The changes in which puberty consists, are for the most part connected with the Reproductive system. The external and internal organs of generation undergo a considerable increase of size; the mammary glands enlarge; and a deposition of fat takes-place in the mammæ and on the pubes, as well as over the whole surface of the body, giving to the person that roundness and fulness, which are so attractive to the opposite sex at the period of commencing womanhood. The first appearance of the Catamenia usually occurs whilst these changes are in progress, and is a decided indication of the arrival of the period of puberty; but it is not unfrequently delayed much longer; and its absence is by no means to be regarded as a proof of the want of aptitude for procreation, since many women have borne large families without having ever menstruated. The Catamenial discharge, as it issues from the uterus, appears to be nearly or quite identical with ordinary blood; but in its passage through the vagina, it becomes mixed with the acid mucus exuded from its walls, which usually deprives it of the power of coagulating. If the discharge should be profuse, however, a portion of its fibrin remains unaffected, and clots are formed. In cases in which, by the death of women at this period, an opportunity has been afforded for the examination of the lining membrane of the uterus during menstruation, it is found to be unusually turgid with blood, the veins in particular being much distended, and opening upon the internal surface by capillary orifices, to which valvules are occasionally found attached.* Hence it is scarcely correct to designate the menstrual flux as a 'secretion;' although there is reason to think that it may carry-off, besides blood, certain matters which would be appropriate to the formation of a Decidual membrane (§ 741), but which, if not so employed, become excrementitious.—The interval which usually elapses between the successive appearances of the discharge, is about four weeks; and the duration of the flow is from three to six days. There is great variety in this respect, however, among the inhabitants of different climates, and among individuals; in general, the appearance is more frequent, and the duration of the flow greater, among the residents in warm countries, and among individuals of luxurious habits and relaxed frame, than among the inhabitants of colder climes, or among individuals inured to bodily exertion. The first appearance of the discharge is usually preceded and accompanied by considerable general disturbance of the system, especially pain in the loins and a sense of fatigue in the lower extremities; and its periodical return is usually attended with the like symptoms, which are more or less severe in different individuals.

731. Much discussion has taken-place respecting the causes and purposes of the Menstrual flow; and recent inquiries have thrown great light upon them. The state of the female generative system, during its continuance, appears to be analogous to the *heat* or periodic sexual excitement of the lower animals; some of which have a sero-sanguinolent discharge at that period, and among many of which the ova are entirely extruded by the female before the spermatic fluid of the male reaches them, this occasionally taking-place even in Birds. There is good reason

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* See Whitehead "On Abortion and Sterility," pp. 18-37.

to believe that in the Human female the sexual feeling becomes stronger at the period of menstruation; and it is quite certain that there is a greater aptitude for Conception, immediately before and after that epoch, than there is at any intermediate period. Observations to this effect were made by Hippocrates, and were confirmed by Boerhaave and Haller; indeed, coitus immediately after menstruation appears to have been frequently recommended as a cure for sterility, and to have proved successful. This question has been made the subject of special inquiry by M. Raciborski; who affirms that the exceptions to the rule—that conception occurs immediately before or after, or during menstruation—are not more than 6 or 7 per cent. Indeed, in his latest work on this subject,* he gives the details of 15 cases, in which the date of conception could be accurately fixed, and the time of the last appearance of the catamenia was also known; and in all but one of them, the correspondence between the two periods was very close. Even in the exceptional case, the catamenia made their appearance shortly after the coitus; which took-place at about the middle of the interval between the two regular periods. When conception occurs immediately before the menstrual period, the catamenia sometimes appear, and sometimes are absent; if they appear, their duration is generally less than usual. The fact that conception often takes-place immediately *before* the last appearance of the catamenia (and not *after* it, as commonly imagined), is one well known to practical men.—Numerous cases have been collected by Mr. Girdwood, Dr. Robert Lee, MM. Gendrin, Negrier, Raciborski, and others, in which the menstrual period was evidently connected with the maturation and discharge of ova;† but the most complete observations yet made on this subject, are those of Dr. Ritchie (loc. cit.). He states that about the period of puberty a marked change usually takes-place in the mode in which the ovisacs discharge their contents; but that this change does not necessarily occur simultaneously with the first appearance of the catamenia; as in some cases, the conditions which obtain in the period before puberty, are extended into that of menstruation. The ovaries now receive a much larger supply of blood; the ovisacs show a great increase in bulk and vascularity, so that, when they appear at the surface of the ovary, they present themselves as pisiform turgid elevations; and the discharge of their contents leaves a much larger cicatrix, and is accompanied by an effusion of blood into their cavity, with other subsequent changes to be presently described. It would appear, however, that although such a discharge takes-place *most frequently* at the menstrual period, yet the two occurrences are not necessarily co-existent; for menstruation may take-place without any such rupture; whilst, on the other hand, the maturation and discharge of mature ova may occur in the intervals of menstruation, and even at periods of life when that function is not taking-place. Perhaps the most correct general statement on the subject would be this: that there is a periodic return of Ovarian excitement, which *tends to* the maturation and extrusion of ovules, though it may not always reach that point; whilst there is also a periodic turgescence of the vessels of the lining membrane of the Uterus, which *tends to* the production of a decidual membrane; —but that these two periods, though usually coincident, are not necessarily so; and that either change *may* occur without the concurrence of the other.

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* "Sur la Ponte des Mammifères," Paris, 1844.

† Such, at least, appears to be the legitimate inference from the state of the Ovaries; but the cases are very few in which the extruded Ova have been found in the female passages. Two such cases (one of them, however, not altogether satisfactory) were recorded by Dr. Letheby, in "Philos. Transact.," 1852.

732. The duration of the period of aptitude for procreation, as marked by the persistence of the Catamenia, is more limited in Women than in Men, usually terminating at about the 45th year; it is sometimes prolonged, however, for ten or even fifteen years further; but cases are rare in which women above 50 years of age have borne children. There is usually no menstrual flow during pregnancy and lactation; in fact, the cessation of the catamenia is generally one of the first signs indicating that conception has taken-place. But it is by no means uncommon for them to appear once or twice subsequently to conception; and in some women there is a regular monthly discharge, though probably not of the usual character, through the whole period. Some very anomalous cases are on record, in which the catamenia never appeared at any other time than during pregnancy, and were then regular. The absence of the catamenia during lactation is by no means constant, especially if the period be prolonged; when the menstrual discharge recurs, it may be considered as indicating an aptitude for conception; and it is well known that, although pregnancy seldom recurs during the continuance of lactation, the rule is by no means invariable.

733. The function of the Female, during the coitus, is essentially passive. When the sexual feeling is strongly excited, there is a considerable degree of turgescence in the erectile tissue surrounding the vagina, and composing the greater part of the nymphæ and the clitoris; and there is an increased secretion from various glandular follicles.* But these changes are by no means necessary for effectual coition; since it is a fact well established, that fruitful intercourse may take-place when the female is in a state of narcotism, of somnambulism, or even of profound ordinary sleep. It has been supposed by some, that the os uteri dilates, by a kind of reflex action, to receive the semen; but of this there is no evidence. The introduction of a small quantity of the fluid just within the vagina, appears to be all that is absolutely necessary for conception; for there are many cases on record in which pregnancy has occurred, in spite of the closure of the entrance to the vagina by a strong membrane in which but a very small aperture existed. That the spermatozoa make

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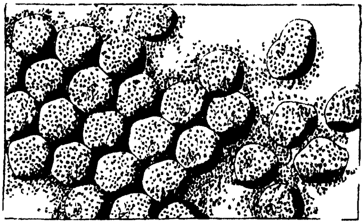
* The glands of Duverney, which were very accurately described by Professor Tiedemann (1840), and subsequently by M. Huguier in the "Archives d'Anatomie" (1847), seem to be analogous to Cowper's glands, and like them are sometimes wanting and differ in size. In advanced age they are said to diminish in size, and even to disappear. They are present in the females of all animals, where Cowper's glands exist in the males. They secrete a thick, tenacious, greyish-white fluid, which is emitted in large quantity at the termination of the sexual act, most likely from the spasmodic contraction of the constrictor vaginæ muscle, under which they lie. Its admixture with the male semen has been supposed to have some connection with impregnation; but no proof whatever has been given that any such admixture is necessary. It seems not improbable, however, that it may serve, like the prostatic fluid of the male, to give a *dilution* to the seminal fluid that is favourable to its action (§ 719). These glands were probably known to the ancients; and it is doubtless their secretion, which Hippocrates and others describe as the female semen.

their way towards the ovarium, and fecundate the ovum either before it entirely quits the ovisac or very shortly afterwards, appears to be the general rule in regard to the Mammalia; and their power of movement must obviously be both vigorous and long continued to enable them to traverse so great an extent of mucous membrane, especially when it is remembered that they ascend in opposition to the direction of the ciliary movement of the epithelial cells, and to the downward peristaltic action of the Fallopian tubes, which may generally be noticed in animals killed soon after sexual intercourse.—We shall now consider the changes in the Ovum and its appendages, by which it is prepared for fecundation.

734. Up to the period when the Ovum is nearly brought to maturity, it remains in the centre of the ovisac or inner layer of the Graafian follicle; and it is supported in its place by the 'membrana granulosa,' which is continuous with its proligerous disk. The movement of the ovum towards the surface, which has been already referred-to as a part of the changes by which it is prepared for fecundation, appears from the observations of Valentin to be due to the following cause:—In the immature ovisac, the space between its inner layer and the ovum is for the most part filled-up with cells; these, however, gradually dissolve-away, especially on the side nearest the surface of the ovary; whilst an albuminous fluid is effused from the deeper part of the ovisac, which pushes the residual layer (forming the discus proligerus) before it, and thus carries it against the opposite wall. At the same time, there is a gradual thinning-away of the various envelopes of the Graafian follicle, as well as of its own walls, in the situation of its most projecting part; and thus it is preparing to give-way at that point, for the discharge of the contained ovum. Before rupture takes place, however, the ovisac itself undergoes a considerable change. Its walls become more vascular externally, and are thickened on their interior by the deposit of a fleshy-looking substance, which in many of the lower Mammalia is of a reddish colour, whilst in the Human female it is rather of a yellowish hue. This substance, known as the *Corpus luteum*, is at first entirely composed of an aggregation of cells (Fig. 158), and may, in fact, be considered as an increased development, or hypertrophy, of the 'membrana granulosa' or epithelial lining of the ovisac; many of its cells, however, especially those in apposition with the enveloping wall of the follicle, undergo a more or less complete transformation into fibres; and thus a gradual transition is established between the cellular substance of the interior of the mass, and the fibrous stroma of the Ovarium itself.* In most domestic quadrupeds, this growth, which sprouts like a mass of granulations from

FIG. 158.



Cells forming the original substance of the *Corpus Luteum*.

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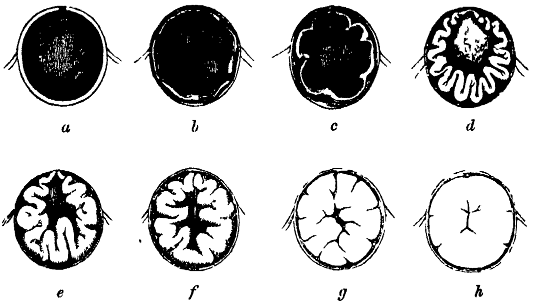
* By some observers, as Kölliker, the principal part of the new growth is regarded as the result of a hypertrophy of the internal layer of the fibrous membrane of the original follicle, which, even before the expulsion of the ovum, becomes loosened in texture and

the lining of the ovisac, is often so abundant, if the ovum be impregnated, as not only to fill the cavity of the ruptured vesicle, but even to protrude from the orifice on the surface of the ovary; this orifice subsequently closes, and the contained growth becomes gradually firmer, its colour changing from red to yellow. In the Human female, however, as in the Sow, this new formation is at first less abundant; it does not form mammillary projections from the interior of the ovisac, but lies as a uniform layer upon its lining; and this is thrown into wrinkles or folds, in consequence of the contraction of the ovisac (Fig. 159, *a*—*d*). An irregular cavity is thus at first left in the interior of the ovisac, after the discharge of the ovum; but this gradually diminishes, partly in consequence of the increased growth of the yellow substance, and partly owing to the general contraction of the ovisac, until it is at last nearly obliterated or reduced to a sort of stellate cicatrix (*e*—*h*). An effusion of blood usually takes place into this cavity, in the Human female, at the time of the rupture of the ovisac; but the coagulum which is left, takes no share in the formation of the yellow body. It generally loses its colouring-matter, and acquires the characters of a fibrinous clot; and this may either form a sort of membranous sac lining the cavity, or it may become a solid mass occupying the centre of the stellate cicatrix.*

FIG. 159.



Successive stages of the formation of the *Corpus Luteum*, in the Graafian follicle of the Sow, as seen in vertical section:—at *a* is shown the state of the follicle immediately after the expulsion of the ovum, its cavity being filled with blood, and no ostensible increase of its epithelial lining having yet taken place; at *b*, a thickening of this lining has become apparent; at *c*, it begins to present folds which are deepened at *d*, and the clot of blood is absorbed *pari passu*, and at the same time decolorized; a continuance of the same process, as shown at *e*, *f*, *g*, *h*, forms the Corpus Luteum, with its stellate cicatrix.

735. The later part of the history of the Corpus Luteum is greatly influenced by the impregnation or non-impregnation of the Ovum whose extrusion it has followed.—If conception do not take-place, the corpus luteum seldoms attains a size greater than that of a small pea, and is very commonly less than this; and it begins to diminish about the time of the next menstruation, its shape, which was at first globular, becoming some-

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augmented in thickness. The fact seems to be, that, as in the case of the Malpighian bodies of the Spleen (§ 130, III.), there is no distinct line of demarcation between the *fibrous wall* and the *cellular contents* of the follicle.

* This process was first accurately described by M. Pouchet, in his "Théorie Positive de l'Ovulation Spontanée," 1847.

what collapsed and flattened. This diminution is due in the first instance to the absorption of part of its contained coagulum, which usually at the same time loses part of its colouring-matter; but contemporaneously with this, there is an increase in the proper yellow substance, which also becomes brighter in colour from the presence of a large quantity of oleaginous matter in its cells. Soon, however, the yellow substance becomes softer and more friable, showing less distinctly the markings of its convolutions; whilst at the same time it becomes more intimately connected with the neighbouring tissues. The central coagulum becomes a faint, whitish, stellate cicatrix; and the yellow substance assumes various irregularities of form, and gradually decreases in size. As a general rule, the corpus luteum of the non-pregnant female is reduced within six or eight weeks to a very insignificant size; but it may then remain almost unchanged for many months; so that, in the ovaries of females who have menstruated regularly, numerous obsolete corpora lutea may be distinguished.—But if, on the other hand, the discharged ovum should be fertilized, and pregnancy should supervene, the corpus luteum, instead of reaching its maximum of development in three or four weeks and then undergoing atrophy, continues to develope itself for a considerable period, and does not, in fact, become very decidedly retrograde, until after the termination of gestation. This difference relates not only to its size, but also to its aspect and general characters. Its size appears to be usually greatest between the third and the sixth months of pregnancy; it retains its globular or only slightly-flattened form; and it continues to give to the touch a sense of considerable resistance and solidity. The convoluted wall of yellow substance becomes much thicker in proportion to the space in its interior; so that whilst in the non-impregnated female its thickness never exceeds one-eighth of an inch, and is usually much less, that of the pregnant female measures as much as from three-sixteenths to one-fourth of an inch. This substance, moreover, acquires a firmer and more highly organized structure; but instead of presenting an increased brightness of colour, it fades to a dusky and indefinite hue. As, from the time that impregnation takes-place, the periodical activity of the ovary is suspended, no new vesicles protrude themselves from its surface until after the completion of gestation; and even those which, at the date of conception, happened to be more or less prominent, appear again to recede. Hence, if the period of pregnancy be at all advanced, the corpus luteum is not found, like that of menstruation, in company with unruptured vesicles in active process of development. After parturition, the corpus luteum rapidly diminishes; though its characteristic structure is still to be distinguished for many months, by close inspection.*

736. The foregoing differences (whose ordinary existence may be considered as well-established, although it may not be affirmed that they present themselves characteristically in each individual case) are probably to be attributed to the increased determination of blood which takes-place to the whole Generative apparatus, when it is in a state of exalted functional activity. It is a question, however, of much scientific interest, and one that occasionally becomes of importance in Juridical investiga-

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* See especially the Prize Essay of Dr. J. C. Dalton, 'On the Corpus Luteum of Menstruation and Pregnancy,' in the "Transact. of the American Medical Association" for 1851, and separately reprinted, Philadelphia, 1851; and the excellent section on 'Reproduction,' in his "Human Physiology," Philadelphia, 1864.

tions, what degree of resemblance may exist between the corpus luteum which is formed after the mere extrusion of an ovule, and that which has been modified by the supervention of pregnancy. For it is unquestionable that an unusual development of the fibro-cellular substance may sometimes occur without impregnation; whilst, on the other hand, the changes which usually follow impregnation may take-place so much less characteristically than usual, that the corpus luteum, even at the middle period of pregnancy, may be no larger than that which is often found where pregnancy has not occurred. These variations, which seem mainly to depend upon differences in the degree of vascular excitement of the ovaries accompanying and succeeding the extrusion of ova, render it impossible to draw any definite line of demarcation, by which we may at once determine what are, and what are not, the results of conception; but the following practical rules, deduced from a consideration of all the circumstances yet known, may be laid down for the guidance of those who find it desirable to have some standard of judgment:—"1. A Corpus Luteum, in its earliest stage (that is, a large vesicle filled with coagulated blood, having a ruptured orifice, and a thin layer of yellow matter in its walls), affords no proof of impregnation having taken-place.—2. From the presence of a Corpus Luteum, the opening of which is closed, and the cavity reduced or obliterated, only a stellate cicatrix remaining, also no conclusion as to pregnancy having existed, or fecundation having occurred can be drawn, if the Corpus Luteum be of small size, not containing as much yellow substance as would form a mass the size of a small pea.—3. A similar Corpus Luteum of larger size than a common pea, would be strong presumptive evidence, not only of impregnation having taken-place, but of pregnancy having existed during several weeks at least; and the evidence would approximate more and more to complete proof, in proportion as the size of the corpus luteum was greater."*

737. Since the discharge of matured Ova from the ovaries takes-place as independently of sexual intercourse in the Human female (and in the Mammalia generally), as it does in those animals whose ova are fertilized out of the body, it seems unnecessary that the seminal fluid should reach the ovarium in order to effect the fertilization of the ova, since this end may be answered by the contact of the two in the Fallopian tubes, or even in the Uterus itself. From the experiments of Bischoff, however, it appears that in rabbits, bitches, and probably in most other Mammalia, sexual union usually takes-place previously to the escape of the ova from the ovary, and that sufficient time often elapses for the seminal fluid to reach the ovary before their extrusion occurs: in such cases, therefore, it would seem probable that fecundation is effected at the ovary itself. That such occasionally happens in the Human female, seems to be unequivocally proved by the occurrence of tubal or even of ovarian fœtation; the ovum having received the fertilizing influence immediately upon quitting the ovisac, or even before it has entirely extricated itself from the ovary, and having been in some way checked in its transit towards the uterus, so that its development has taken-place in the spot at which it has been arrested. It is affirmed by Bischoff that by the time the ovum reaches the uterus, or even the lower end of the Fallopian tube, its capacity for impregnation is lost; but this assertion chiefly rests on the cessation of sexual desire

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* See Dr. Baly's "Supplement to Müller's Physiology," p. 57.

observed in those animals in which, after death, the ova were found in these situations. There is every reason to believe that this is not the case in the Human female; for although the sexual desire may be the strongest about the period of the maturation and escape of the ova, yet it is by no means wanting at other times; and the occasional occurrence of cases in which impregnation has taken-place from a single coitus in the middle of the interval between the menstrual periods, shows either that the ovum may retain its capacity for impregnation for some time after its escape from the ovary, or that its maturation and extrusion are not by any means invariably coincident with the menstrual period.*—The ova, when set-free from the ovaries by the rupture of the ovisacs and the giving-way of their several envelopes, and surrounded by the cells of the membrana granulosa, are received by the fimbriated extremities of the Fallopian tubes, which, during the period of sexual excitement, appear to be closely applied to the surface of the ovaries. Their conveyance along the Fallopian tubes is probably due in part to the peristaltic movement of their walls, and in part to the action of the cilia which clothe their internal surface.

738. The object of the changes which have been already described, is to bring the Ovum within the reach of the fecundating influence, and to convey it into the uterus after it has been fertilized: we have now to consider the changes of the Ovum itself, which take-place during the same epoch.—At about the same period that the ovum moves towards the periphery of the Graafian follicle, the germinal vesicle moves towards the periphery of the yolk; and it always takes-up its position at the precise point of the zona pellucida which is nearest the ovisac, and which is closest, therefore, to the surface of the ovary. Moreover, the germinal spot is always on that part of the germinal vesicle, which is in closest contact with the zona pellucida. Thus, the germinal spot is very near the exterior of the ovary; but it is separated from the peritoneal coat of the latter, by a thin layer of its stroma forming the external wall of the Graafian follicle, by the ovisac forming its internal membrane, and by the zona pellucida. As soon as these give-way, there is nothing to prevent the spermatozoa from coming into direct contact with the ovum, even before it quits the ovisac. That such contact is an essential condition of fecundation, there is every reason to believe; although, as to the precise manner in which it operates, we are at present in the dark. There can be no doubt that it is in the contact of the spermatozoa with the ovum (§ 722), and in the changes which occur as the immediate consequence of that contact, that the act of Fecundation essentially consists. The most recent observations of the late Mr. Newport upon the process of impregnation of the Frog (some of which the Author, through the kindness of Mr. N., had the opportunity of verifying) showed that the spermatozoa become imbedded in the gelatinous envelope of the ovum, within a few

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* See a case of this kind recorded by Dr. Oldham in the "Medical Gazette," July 13, 1849.—Instances are certainly not unfrequent, in which conception has taken-place five or six days after the conclusion of the menstrual period; the Author has himself known one in which this occurred, after the menstrual flow itself had persisted for a week. It has been urged that the known fertility of Jewish females, who abstain from sexual intercourse for eight days, or even thirteen days, after the termination of the catamenia, is opposed to the idea that the menstrual period is that of 'heat;' but there is reason to believe that this is to be accounted-for in another way,—namely, by the usual occurrence of conception from intercourse immediately *before* the access of the catamenia. (See Mr. Girdwood, in the "Lancet," Dec. 14, 1844.)

seconds after they come into contact with it; and that they then absolutely pass through the vitelline membrane, into the interior of the Ovum,* where they probably undergo a gradual diffluence; and thus the product of the 'sperm-cell' may be absorbed into the 'germ-cell,' and may intermingle with its contents, the Spermatozoon being nothing else than an embodiment of the fertilizing material developed within the sperm-cell, which is endowed with a temporary power of movement in order that it may find its way to the Ovum.—In the Osseous Fishes it has been shown by Dr. Ransome that the Spermatozoa pass-through a minute opening in the external membrane of the ova, termed the micropyle. A similar opening has been observed by Müller and others in Insects, Acephalous Mollusks, and in several Echinodermata; and its use, as Dr. Allen Thomson has suggested, is probably to facilitate the fecundation of ova possessed of very thick external coverings. A micropyle has not been seen in any of the Mammalia, though the point has been closely investigated by Reichert in the Guinea Pig. It has been remarked by Mr. Newport, that Spermatozoa whose spontaneous *motility* has ceased, no longer possess the fecundating power; and this fact concurs with other phenomena to indicate, that it is not only a certain *material*, but a *vital force* of which that material is (so to speak) the vehicle, which is required to effect this most important operation.

739. The precise share which the Germinal Vesicle performs in the changes which take-place in the ovum about the period of fecundation, has not yet been satisfactorily determined. According to Dr. Barry (loc. cit.), the germinal vesicle becomes filled with a new development of cells, which sprout, as it were, from its nucleus (the germinal spot); and after fecundation, a pair of cells is seen in the space previously occupied by the pellucid centre of the nucleus, which is developed at the expense of the rest, and is the true foundation of the embryonic structure. This view is to a certain extent confirmed by the observations of Wagner on the ova both of Frogs and Mammalia, and by those of Vogt on those of the *Rana obstetricans*; both of which lead to the belief that such a process of cell-formation does take-place within the germinal vesicle, but that, instead of the further development being carried-on within the germinal vesicle, as maintained by Dr. Barry, this ruptures and sets-free the cells that had been developed in its interior, which are now dispersed through the yolk, whose ulterior changes take-place under their influence. Mr. Newport's view is nearly the same as this; and he states that, in the Frog, this dissolution of the germinal vesicle and diffusion of its contents take-place as a preparation for fecundation, and not in consequence of it.† That the germinal vesicle is no longer to be seen when the metamorphoses of the yolk have commenced, is now universally admitted; but with regard to the antecedent process just described, there is still a want of accordance amongst Embryologists, its existence being altogether denied by Bischoff, who maintains that the germinal vesicle simply dissolves-away shortly

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* "Philos. Transact.," 1853, pp. 266–281.—Prof. Bischoff, the highest authority on this subject, who had disputed the validity of all previous observations on the penetration of the Spermatozoa into the interior of the Ovum, fully confirmed those of Mr. Newport; whose lamented death prevented him from enjoying the satisfaction which this testimony to his accuracy would have afforded him.—See also Dr. Barry, in "Philos. Transact.," 1840, p. 533; and Dr. Ransome, in "Proceed. of Roy. Soc.," Nov. 23, 1854.

† "Philos. Transact.," 1851, p. 178.

after coition. The Author is strongly inclined to believe, however, from his own observations, as well as from *à priori* considerations based on the history of Vegetable fertilization, that there *is* a development of cells within the germinal vesicle, at the time of its maturation; and that it is by the influence of the spermatic fluid upon one of these cells, after it has been set-free in the midst of the yolk by the rupture or diffluence of the germinal vesicle, that the first cell of the embryonic fabric is generated.*

740. Having thus noticed the principal points of the history of the development and impregnation of the Ovum, we shall proceed to consider the provisions made for the Nutrition of the Embryo, through the Generative apparatus of its female Parent, up to the time of parturition; deferring the history of its own Development for that separate consideration which the importance of this subject demands (Sect. 4).—About the time that the ovum is leaving the ovary, the cells of the proligerous disk which immediately surrounds the zona pellucida become club-shaped; their small ends being applied to the surface of the ovum, so as to give it somewhat of a stellate appearance. According to Bischoff, these cells entirely disappear from the ovum of the Rabbit as soon as it has entered the Fallopian tube: whilst in the Bitch they become round, and continue to invest the ovum in this form throughout its whole transit to the uterus. During its passage, the ovum acquires a sort of gelatinous envelope, which is enclosed in a membrane of fibrous texture, termed the *Chorion.* This envelope is probably of an *albuminous* nature in reality, corresponding with the 'white' of the Bird's egg; whilst the fibrous texture of the chorion seems to be produced, like the membranous basis of the egg-shell of the bird, by the exudation of fibrin from the lining membrane of the Fallopian tube or oviduct. The outer layer of this envelope, in the egg of the Bird, is consolidated by the deposition of particles of carbonate of lime in its areolæ; and none of it undergoes any further organization. The Chorion of the Mammal, on the other hand, is destined to undergo changes of a much higher order, which adapt it for participating to a most important degree in the nutrition of the included embryo. The first of these changes consists in the extension of the cellular surface of the membrane into a number of villous prolongations, which give it a spongy or shaggy appearance (Fig. 163); these serve as absorbing radicles, and form the channel through which the embryo is nourished by the fluids of the parent, until a more perfect communication is formed by the subsequent extension of vessels into them.

741. We have now to speak of the changes in the Uterus which take-place in consequence of Conception, and which prepare it to receive the ovum. Of these the most important is the formation of the Membrana *Decidua*, so called from its being cast-off at each parturition. This membrane has been usually supposed to be a new formation; and has been described as originating in coagulable lymph thrown-out on the inner surface of the uterus, into which vessels are prolonged from the subjacent substance. It appears, however, from the researches of Profrs. Sharpey and Weber,† that this is not the true account of it; and that the

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* See Huxley on 'Development of Pyrosoma,' in "Linn. Trans.," vol. xxiii. p. 227; and "Ann. Nat. Hist.," Ser. 3, vol. v. pp. 29-35.

† Müller's "Elements of Physiology," pp. 1574-1580. See also the article 'Uterus and its Appendages,' by Dr. A. Farre, in "Cyclop. of Anat. and Physiology," supple-

Decidua vera is really composed of the inner portion of the Mucous membrane itself, which undergoes a considerable change in its character. The Uterus is lined by columnar ciliated epithelium, which according to Robin* is partly exchanged during the progress of pregnancy for the tesselated variety and partly desquamates; it presents also on its free surface a tubular structure (Figs. 160, 161); not very unlike that which has been described as existing in the lining membrane of the stomach (§ 81). This tubular portion becomes thickened and increased in vascularity, within a short time after conception; and when the inner surface of a newly-impregnated Uterus is examined with a low magnifying power, the orifices of its tubes are very distinctly seen, being lined with a white epithelium. The blood-vessels form a very minute network, which extends in loops from the subjacent portion of the membrane. According to the observations of Prof. Goodsir† and Schroeder v. der Kolk, the interfollicular spaces are crowded with fat molecules and nucleated particles; and it is to the development of this interfollicular substance, as

FIG. 160.

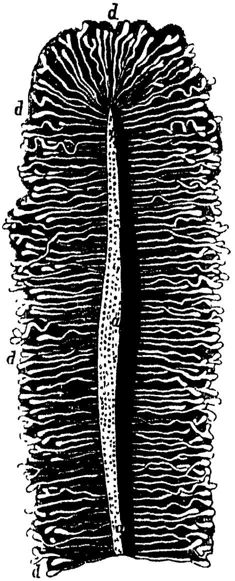

FIG. 161.

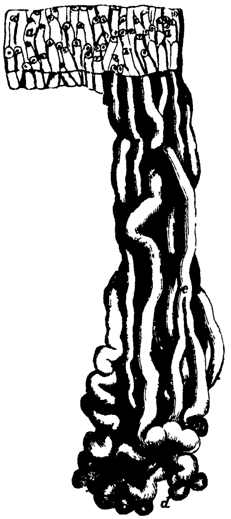

Fig. 160. Section of the *Lining Membrane of a Human Uterus* at the period of commencing pregnancy, twice the natural size; showing the arrangement and other peculiarities of the glands, *d*, *d*, *d*, with their orifices, *a*, *a*, *a*, on the internal surface of the organ.

Fig. 161. A portion of Fig. 160 more enlarged, showing the convoluted extremities of the tubular glandulæ.

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mentary volume, p. 655; and the Lectures of Dr. Priestley 'On the Gravid Uterus,' in the "Med. Times and Gazette," 1858, vol. ii.

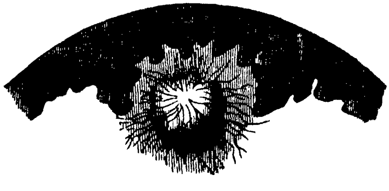
* Brown-Séquard's "Journal de la Physiologie," vol. i. 1858, p. 60.

† "Anatomical and Physiological Observations," chap. ix.

well as to the enlargement of the follicles themselves, and the copious development of epithelial cells in their interior, that the mucous membrane in this condition owes its increased thickness. This increased development appears to have reference in part to the temporary nutrition of the Ovum, and in part to the further evolution of the decidual substance itself in the formation of the Placenta. The cavity of the Uterus shortly becomes filled with a fluid, evidently poured-out from the follicles in its walls, and containing a large number of nucleated cells; and in this the villi of the chorion imbed themselves, obviously for the purpose of deriving from it the materials required for the development of the embryonic structures. These villi are easily traced in the Bitch (as Dr. Sharpey first pointed-out) into the mouths of the uterine glandulæ, some of which are composite in their structure, a single outlet being common to a number of follicles; but they have not yet been so traced in the Human subject.

742. The Deciduous membrane is found at a later period to consist of two layers: the *Decidua vera* lining the uterus, and the *Decidua reflexa* covering the exterior of the ovum. Regarding the origin of this second layer, there has been a good deal of difference of opinion. The doctrine first propounded by Dr. W. Hunter, which is indicated by the name he bestowed upon the membrane, was that the 'decidua reflexa' is a portion of the true decidua, which has been pushed before the ovum at its entrance into the uterus; it being supposed that the true decidua forms a completely closed sac (like that of a serous membrane), against the *outside* of which the ovum is applied, so that it comes to be invested by a double layer of it, as the heart is by the pericardium, or the lungs by the pleura. But this view is negatived by a number of considerations. For, in the first place, the original decidua does not form the closed sac which this supposition involves, but extends (like the mucous membrane of which it is a metamorphosed form) into the Fallopian tubes; and the ovum, at its entrance into the uterus, really lies upon its internal surface. But again, the texture of the two layers is very different; for, as was first pointed-out by Prof. Goodsir (loc. cit.), the decidua reflexa is almost entirely composed of cells, exhibiting few or none of the orifices of the glandular follicles which are characteristic of the decidua vera, except near the part where the two layers are continuous. Ramifying on its surface are numerous flat vessels, described by Dr. A. Farre as venous channels, which with their minute subdivisions give a pink tinge to the whole surface. According to the observations of M. Coste and Dr. Arthur Farre, however, there is a considerable resemblance between the two layers at an early period; and they consider the following to be the mode in which the second investment is formed:—When the ovum enters the uterus, it becomes partially imbedded in the substance of the decidua, which is as yet quite soft (Fig. 162); and this,

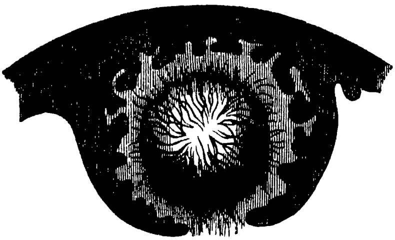
Fig. 162.



First stage of the formation of the *Decidua reflexa* around the Ovum.

receiving an increased nutrition at the part with which the ovum comes into contact, grows-up around it, very much after the manner in which the fleshy granulations grow up around the pea imbedded in a caustic issue. This extension of the decidual substance continues (Fig. 163), until it has completely enveloped the ovum; and it is thus, according to them, that the decidua reflexa is formed, in continuity with the decidua vera.* As the ovum increases in size, the cavity between the decidua vera and the decidua reflexa, or, as it is sometimes termed, the uterine chamber, gradually diminishes, and by the end of the third month either the two layers come into contact and are henceforth indistinguishable—the whole cavity of the uterus being occupied by the fœtal chamber—or, as Dr. Farre suggests, the decidua reflexa may, after first becoming extremely attenuated, ultimately entirely vanish.

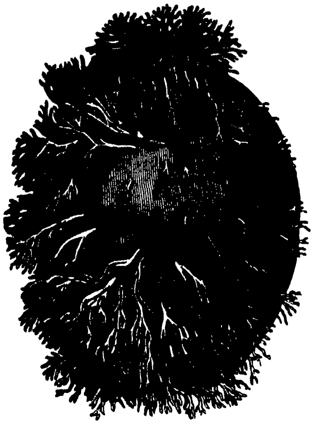
Fig. 163.



More advanced stage of *Decidua reflexa.*

743. The surface of the Ovum, thus surrounded by the double layer of the deciduous menbrane, and during the first three or four weeks lying loose in the fœtal chamber, is rendered shaggy by the growth of villous tufts from the surface of its investing Chorion (Fig. 164), by which it begins to be attached to the walls that surround it. Each of these tufts, as was first pointed-out by Prof. Goodsir (loc. cit.), is composed of an assemblage of nucleated cells, which are found in various stages of development; and these are always enclosed within a layer of basement-membrane, which seems to be itself composed of flattened cells united by their edges. At the free extremity of each villus is a bulbous expansion, the cells composing which are arranged round a central spot; and it is at this point that the most active processes of growth take-place, the villus elongating by the development of new cells from its germinal spot, and

Fig. 164.



Entire *Human Ovum* of 8th week, sixteen lines in length (not reckoning the tufts); the surface of the Chorion partly smooth, and partly rendered shaggy by the growth of tufts.

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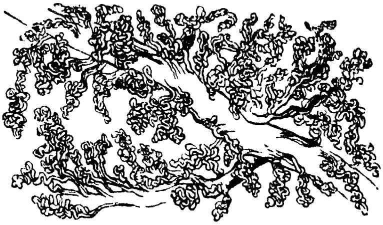
* This doctrine was first announced by M. Coste, in a communication to the Parisian Academy of Sciences, on the basis of observations on two Uteri at the 20th and 25th days of gestation. (See "Comptes Rendus," Mai 24, 1847.) It seems to be that which is altogether most in harmony with observed facts; and especially with those noticed by Professors Sharpey and Weber.—See, also, the Memoir of M. Robin, on the Mucous Membrane of the Uterus, in the "Archiv. Gén. de Méd.," 4e Sér., tom. xvii. xviii.

(like the spongiole of the plant) drawing-in nutriment from the soil in which it is imbedded.—In its earliest grade of development, the chorion and its villi contain no vessels; and the fluid drawn-in by the tufts is communicated to the embryo by the absorbing powers of the germinal membrane of the latter. But when the tufts are penetrated by blood-vessels, and their communication with the embryo becomes more direct, the means by which they communicate with the parent are found to be still essentially the same; namely, a double layer of nucleated cells, one layer belonging to the fœtal tuft, and the other to the vascular maternal surface. It is from these elements that the *Placenta* is formed.

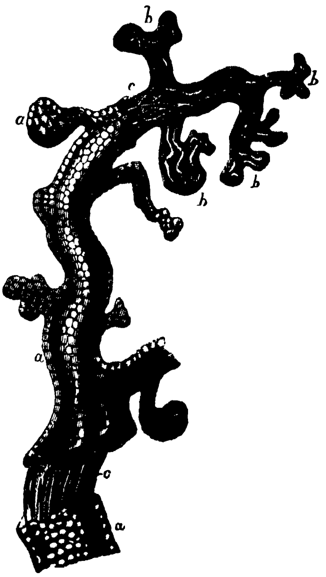
Fig. 165.



Portion of the ultimate ramifications of the Umbilical vessels, forming the *Fœtal Villi of the Placenta.*

744. The first stage in this process consists in the extension of the Fœtal vessels into the villi of the Chorion over its entire surface, in the manner hereafter to be detailed; so that the nutriment which these villi imbibe, instead of being merely added to the albuminous fluid surrounding the yolk-bag, is now conveyed directly to the embryo. This—the earliest and simplest mode by which the Fœtus effects a new connection with the parent—is the only one in which it ever takes-place in the lower Mammalia, which are hence properly designated as 'non-placental,' rather than as ovo-viviparous. In the higher Mammalia, however, there soon occurs a great extension of the vascular tufts of the fœtal chorion, at certain points; and a corresponding adaptation, on the part of the uterine structure, to afford them an increased supply of nutritious fluid. These specially prolonged portions are scattered, in the Ruminantia and some other Mammalia, over the whole surface of the chorion, forming what are termed the 'cotyledons;' but in the higher orders, and in

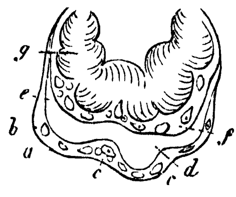
Fig. 166.



Portion of one of the *Fœtal Villi*, about to form part of the Placenta, highly magnified:—*a, a*, its cellular covering; *b, b, b*, its looped vessels; *c, c*, its basis of connective tissue.

Man, they are concentrated in one spot, forming the Placentà. In some of the lower tribes the maternal and the fœtal portions of the placenta may be very easily separated; the former consisting of the thickened Decidua, and the latter being composed of the prolonged and ramifying muscular tufts of the Chorion, dipping-down into it. But in the Human placenta, the two elements are mingled together through its whole substance.—On looking at the fœtal surface of the Human placenta, we perceive that the umbilical vessels diverge in every direction from the point at which they enter it; and their subdivisions form a large mass of capillaries, arranged in a peculiar manner (Figs. 165, 166), and constituting what are known as the *fœtal villi.* Each villus contains one or more capillary loops, communicating with an artery on one side, and with a vein on the other; but the same capillary may pass into several villi, before re-entering a larger vessel. The capillaries of the villi are covered, as in the chorion, by a layer of cells (Fig. 166, *a*, *a*, Fig. 167, *f*), inclosed in basement-membrane (*e*); but the fœtal tuft thus formed is inclosed in a second series of envelopes (Fig. 167, *a*, *b*, *c*), derived from the maternal portion of the placenta,—a space (*d*) being left, however, between the two, at the extremity of the tuft.

FIG. 167.



Extremity of a *Placental Villus*:—*a*, external membrane of the villus, continuous with the lining membrane of the vascular system of the mother; *b*, external cells of the villus, belonging to the placental decidua; *c*, *c*, germinal centres of the external cells; *d*, the space between the maternal and fœtal portions of the villus; *e*, the internal membrane of the villus, continuous with the external membrane of the chorion; *f*, the internal cells of the villus, belonging to the chorion; *g*, the loop of umbilical vessels.

745. Whilst the *fœtal* portion of the Placenta is thus being generated by the extension of the vascular tufts of the Chorion, the maternal portion is formed by the enlargement of the vessels of the Decidua, between which they dip-down. "These vessels assume the character of sinuses; and at last swell-out (so to speak) around and between the villi; so that finally the villi are completely bound-up or covered by the membrane which constitutes the walls of the vessels, this membrane following the contour of all the villi, and even passing to a certain extent over the branches and stems of the tufts. Between this membrane, or wall of the enlarged decidual vessels, and the internal membrane of the villi, there still remains a layer of the cells of the decidua."* In this manner is formed the *maternal* portion of the placenta, which may be regarded in its adult state (as was well pointed-out by Dr. J. Reid†) in the light of a large sac formed by a prolongation of the inner coat of the uterine vessels; against the fœtal surface of which sac the tufts just described may be said to push themselves, so as to dip-down into it, carrying before them a portion of its thin wall, which constitutes a sheath to each tuft. Now as every extension of the uterine vessels carries the decidua before it, every one of the vascular tufts that dips-down into it will be covered with a layer of the cellular structure of the latter; and the fœtal portion of each tuft will

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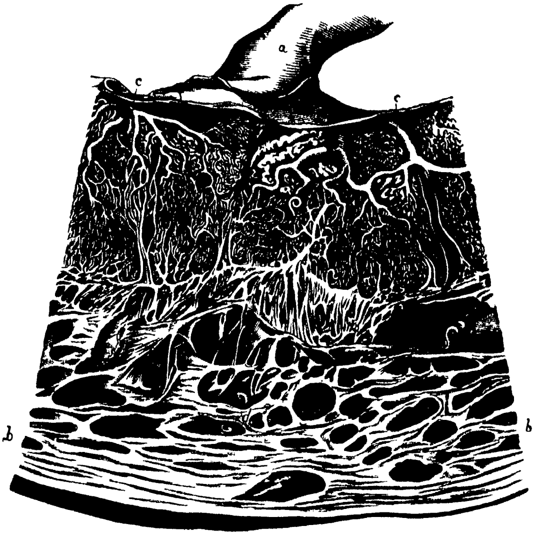
* Prof. Goodsir's "Anatomical and Pathological Observations," p. 60.

† "Edinb. Med. and Surg. Journ.," Jan. 1841; and "Anat., Phys., and Pathol. Researches," chap. viii.

thus be inclosed in a layer of *maternal* cells and basement-membrane (Fig. 167, *a*, *b*, *c*). Dr. A. Farre is, however, of opinion that the maternal vascular walls are not continued into the sinuses of the placenta. He believes the blood in the interior of the placenta to be as much external to the maternal vascular system as it is while passing through a quill inserted between the divided ends of a vein in the living animal.* However this may be, the whole interior of the Placental cavity becomes (Fig. 168) intersected by numerous tufts of fœtal vessels disposed in fringes, and bound-down by reflexions of the delicate membrane that forms its proper wall; just as the intestines are held in their places by the reflexions of

FIG. 168.



Section of a portion of a fully-formed *Placenta*, with the part of the Uterus to which it is attached —*a*, umbilical cord, *b*, *b*, section of uterus, showing the venous sinuses; *c*, *c*, *c*, branches of the umbilical vessels, *d*, *d*, curling arteries of the uterus.

FIG. 169.

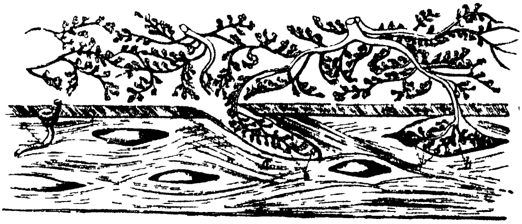


Diagram of the structure of the *Placenta* —showing, *a*, the substance of the uterus; *b*, the cavity of a sinus; *c*, curling arteries; *d*, *d*, the decidual lining of the uterus; *e*, *e*, the fœtal tufts dipping-down into this.

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* Loc. cit. p. 722.

the peritoneum that covers them. This view was suggested to Dr. Reid by the very interesting fact, that the tufts of fœtal vessels not unfrequently extend beyond the uterine surface of the placenta, and dip-down into the uterine sinuses (Fig. 169); where they are still covered and held in their places by reflexions of the same membrane. All the bands which connect and tie-down the tufts are formed of the same elements as the envelopes of the tufts themselves; namely, a fold of the lining membrane of the decidual sinuses, and a layer of the cellular decidua.

746. The Maternal blood is conveyed into the Placental cavity by the 'curling arteries' of the uterus (Fig. 168, *d*, Fig. 169, *c*); and is received-back from it into the large veins that are commonly designated as sinuses (Figs. 168, 169, *b*, *b*). The fœtal vessels (Fig. 168, *c*, *c*, Fig. 169, *e*, *e*) being bathed in this blood, as the branchiæ of aquatic animals are in the water that surrounds them, not only enable the fœtal blood to exchange its venous character for the arterial, by parting with its carbonic acid to the maternal blood, and receiving oxygen from it; but they also serve as rootlets, by which certain nutritious elements of the maternal blood (probably those composing the liquor sanguinis) are taken into the system of the fœtus. In this, they closely correspond with the villi of the intestinal canal; and there is this further very striking analogy,—that the nutrient material is selected and prepared by two sets of cells, one of which (the maternal) transmits it to the other (the fœtal), in the same manner as the epithelial cells of the intestinal villi seem to take-up and prepare the nutrient matter, which is destined to be still further assimilated by the cells that float in the circulating current (§ 107). It is probable, too, that the Placenta is to be regarded as an excreting organ; serving for the removal, through the maternal blood, of excrementitious matter whose continued circulation through the blood of the fœtus would be prejudicial to the latter. And it will be in this mode that the blood of the mother may become impregnated with substances, or impressed with attributes, originally belonging to the male parent; so as to impart these to the products of subsequent conceptions by a different father (§ 759).* There is no more direct communication between the mother and fœtus than that which is afforded by this immersion of the fœtal tufts in the maternal blood; all the observations which have been supposed to prove the existence of real vascular continuity, having been falsified by the extravasation of fluid, probably consequent upon the force used in injecting the vessels. Moreover, the different size of the blood-corpuscles in the fœtus and in the parent (§ 156) shows the non-existence of any such communication.

747. The formation of the Placenta, in the manner just described, commences in the latter part of the second month; during the third, the organ acquires its proper character; and it subsequently goes-on increasing, in accordance with the growth of the Ovum. Towards the end of the term of gestation, however, it becomes more dense and less vascular; owing, it would seem, to the obliteration of several of the minuter vessels, which are converted into hard fibrous filaments. The

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* See, for various proofs that the mother may be *poisoned* through the presence of noxious substances in the blood of the fœtus, the Essay by Mr. Savory, entitled "An Experimental Inquiry into the Effect upon the Mother of Poisoning the Fœtus," London, 1858.

vessels of the Uterus undergo great enlargement throughout, but especially at the part to which the placenta is attached; and the blood in moving through them produces a peculiar murmur, which is usually distinctly audible at an early period of pregnancy, and may be regarded (when due care is taken to avoid sources of fallacy), as one of its most unequivocal positive signs. The 'placental bruit' is thus described by Dr. Montgomery:*—"The characters of this phenomenon are, a low murmuring or somewhat cooing sound, resembling that made by blowing gently over the lip of a wide-mouthed phial, and accompanied by a slight rushing noise, but without any sensation of impulse. The sound is, in its return, exactly synchronous with the pulse of the mother at the time of examination; and varies in the frequency of its repetitions, with any accidental variation which may occur in the maternal circulation. Its situation does not vary during the course of the same pregnancy; but in whatever region of the uterus it is first heard, it will in future be found, if recognized at all,—for it is liable to intermissions,—at least, we shall occasionally be unable to hear it where we have already heard it a short time before, and where we shall shortly again recognize it. According to my experience, it will be most frequently heard about the situation of the Fallopian tube of the right side; but it may be detected in any of the lateral or anterior parts of the uterus." That the cause of this sound exists in the Uterus itself, is distinctly proved by the fact, that it has been heard when that organ was so completely *anteverted*, that the fundus hung-down between the patient's thighs. A sound so much resembling this as to be scarcely distinguishable from it, may be occasioned, however, by a cause of a very different nature,—namely, an abdominal tumour, pressing upon the aorta, iliac arteries, or enlarged vessels of its own; and, in doubtful cases, it is necessary to give full weight to the possibility of such an explanation. The sound may be imitated at any time, by pressing the stethoscope on the iliac arteries. The placental bruit has been not unfrequently heard in the eleventh week; but it cannot generally be detected before the fourth month, when the fundus uteri rises above the anterior wall of the pelvis.

748. The increase in the size of the Uterus, which takes-place *pari passu* with the enlargement of the ovum, is accompanied with a remarkable augmentation in the amount of its substance. Up to about the fifth or sixth month, not only its cavity, but the thickness of its walls, is progressively added-to; from that time to the end of gestation, the thickness of the walls diminishes whilst the cavity increases, but not in an equal proportion; and at the conclusion of parturition, its solid bulk is estimated at about twenty-four times that of the unimpregnated Uterus. The augmented volume of the organ is chiefly due to the increased development of its Muscular coat, which is composed of the fusiform cells with staff-shaped nuclei, that make-up the 'non-striated' muscular fibre elsewhere. According to Prof. Kölliker, a vast amount of new fibres are generated during the early months of pregnancy; but there is at the same time an extraordinary increase in the size of those previously formed, their length being multiplied from seven to eleven times, and their width from twice to five times. After the sixth month the origination of new muscular fibres seems to cease, but the augmentation in the size of those

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* "Signs of Pregnancy," p. 121.

already generated seems to continue. The connective tissue which unites the muscular fibres also increases during pregnancy, and becomes more distinctly fibrous.* It has been affirmed that the Nervous substance of the Uterus also undergoes a great augmentation during pregnancy; but of this no sufficient evidence has yet been adduced. Simultaneously with the enlargement of the uterus, the Mammary Gland and its appendages undergo a fuller development; and from this a valuable, but not unequivocal, indication of pregnancy may be drawn. Occasional shooting pains in the Mammæ are not unfrequently experienced within a short period after conception; and more continued tenderness is also not unusual. A sense of distension is very commonly experienced at about the end of the second month; and from that time a distinct 'knottiness' usually begins to present itself, increasing with the advance of pregnancy. In many instances, however, these mammary sympathies are entirely absent; and they may be simulated by changes that take-place in consequence of various affections of the uterus. A change of colour in the areola is a very common, but not an invariable, occurrence in the early months of pregnancy; but another sign is afforded by the areola and nipple, which is of more value because more constant,—namely, a puffy turgescence, and an increased development of the little glandular follicles, or tubercles, which commonly secrete a dewy moisture.—Many other changes in the constitution occur during pregnancy; indicated by the buffiness of the blood, the irritability of the stomach, and the increased excitability of the mind. All these, however, are discussed with sufficient amplification, in works on Obstetric Medicine.

749. The act of Conception, being one of a purely organic nature, is not itself productive of any sensation on the part of the mother; but there are some women in whom it is attended with certain sympathetic affections, such as faintness, vertigo, &c., that enable them to fix upon the particular time at which it has taken place. From that period, however, the mother has no direct consciousness of the change going-on in the uterus (save by the effects of its increasing pressure on other parts), until the occurrence of what is termed 'quickening.' This is generally described as a kind of fluttering movement, attended with some degree of syncope or vertigo. After it has once occurred, and has strongly excited attention, it is occasionally renewed once or twice, and then gives place to the ordinary movements of the fœtus. Not unfrequently, however, no movement whatever is felt, until near the end of the term of gestation, or even through the whole of it. As to the cause of the sensation, Obstetricians are much divided; and no satisfactory account has been given of it. It has been vulgarly supposed to be due to the first movement of the fœtus, which was imagined then to become possessed of an independent life; and the English law recognizes the truth of this doctrine, in varying the punishment of an attempt to procure Abortion, according to whether the woman be 'quick with child' or not; and in delaying execution when a woman can be proved to be so, though it is made to proceed if she is not, even if she be unquestionably pregnant. Whether or not the first *sensible* motions of the fœtus are the cause of the peculiar feeling in question, there can be no doubt that the embryo has

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* See Kölliker's "Manual of Human Histology" (Sydenham Society's Ed.), vol. ii. pp. 258, 259.

as much independent vitality before, as after, the quickening. From the time that the ovum quits the ovary, it ceases to be a part of the parent, and is dependent on it only for a due supply of nourishment, which it converts by its own inherent powers, into its proper fabric. But this dependence cannot be said to cease at the moment of quickening; for the connection must be prolonged during several weeks, before the fœtus becomes capable of sustaining life without such assistance. The earliest period at which this may occur, will be presently considered (§ 754).

750. At the conclusion of about forty weeks, or (less correctly) nine solar months,* from the period of conception, the time of Parturition arrives. In this act, the muscular walls of the Uterus are primarily concerned; for a kind of peristaltic contraction takes-place in them, the tendency of which is to press the contents of the cavity from the fundus towards the os uteri, and finally to expel them; and this contraction is alone sufficient to empty the uterus, when no impediment is presented to the exit of the fœtus, as we see in the occasional occurrence of *post-mortem* parturition. It is, in fact, in the contraction of the fibres of the fundus and body of the uterus, and in a relaxation of those about the cervix (which relaxation is something quite different from a mere yielding to pressure, and is obviously a vital phenomenon that marks a peculiarity in the actions of this part), that the first stage of an ordinary labour essentially consists.† There is no proof whatever that these changes are dependent upon nervous influence; in fact, there is much evidence that the parturient action of the uterus is *not* the result (as some have maintained it to be) of a 'reflex' action of the Spinal Cord, but is due to its inherent contractility; for numerous instances have occurred in which normal parturition has taken-place, notwithstanding the destruction of the lower part of the Cord, or the existence of a state of complete paraplegia which marked its functional inactivity; and the continuance of the peristaltic action for some time after somatic death, when neither the Cerebro-spinal nor the Sympathetic system can afford any supply of nervous power, is a yet more satisfactory proof of the same position.—Nevertheless, it seems quite certain that muscular contractions of the Uterus *may be* induced by reflex action; for in no other way can we account for numerous phenomena, which distinctly mark the operation of remote causes acting through the nervous system; such as the induction of uterine contractions by the dash of cold water on the abdominal surface, by the injection of cold water into the vagina, by the ingestion of cold water into the stomach, or even by dipping the hands

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* Although 'nine months' is usually spoken-of as the term of Gestation, yet the real term of forty weeks exceeds this by from five to seven days, according to the months included. The mode of reckoning customary among women, is to date from the middle of the month after the last appearance of the Catamenia ; but it is certain that Conception is much more likely to take-place *soon* after they have ceased to flow, or even just before their access, than in the intervening period (§ 731) ; so that, in most instances, it would be most correct to expect labour at forty weeks and a few days after the last recurrence of the Menses.—The period of Quickening may be relied-on in some women, in whom it occurs with great regularity in a certain week of pregnancy ; but in general there is great latitude as to the time of its occurrence. The usual or average time seems to be about the 18th week of gestation.

† See a paper corroborating this statement, by Arthur Scott Donkin, M.D., in "Edinb. Med. Journal," vol. ii. 1863, p. 523.

into cold water, or again by the suctorial application of the infant's lips to the nipple, by the introduction of the hand into the vagina, by violent movements of other parts of the body, and by various other means. This general fact has an important practical bearing; since there are various occasions on which it is most important to life that the previously-flaccid uterus should be excited to vigorous contraction, for the sake of accelerating parturition or of suppressing hæmorrhage; whilst, on the other hand, it is often no less important to be able to prevent or to antagonize the operation of causes which would prematurely induce uterine contractions, to the destruction of the offspring and the danger of the mother.

751. When, in the normal act of Parturition, the head has so far made its way through the os uteri as to begin to distend the lower part of the genital canal, a new kind of expulsive effort is superadded to that of the Uterus itself; the assistance of the Expiratory muscles being then called in (§ 495), through the intermediation of the Spinal Cord, which is probably excited to this action by the stimulus thus applied to the afferent nerves of the compressed parts; and it is chiefly by the instrumentality of these muscles that the normal act of parturition is usually completed. The same action which expels the fœtus, generally also detaches the placenta; and if the uterus contract with sufficient force after this has been thrown-off, the orifices of the vessels which communicate with it are so effectually closed, that little or no hæmorrhage takes-place. If, however, the uterus does not contract, or relaxes after having contracted, a large amount of blood may be lost in a short time from the open orifices. For some little time after parturition, a sero-sanguineous discharge, termed the *lochia*, is poured-out from the uterus; and this commonly contains shreds of the deciduous membrane which had not been previously detached, together with a quantity of fat-globules, and other products of disintegration of the uterine tissue (§ 333).* Within a few weeks after delivery, the uterus regains (at least in a healthy subject) its previous condition; part of its newly-generated muscular fibres seem to disappear altogether, whilst the others shrink to their ordinary dimensions; and the portion of its mucous membrane which had been thrown-off as Decidua, seems to be to some extent reproduced, according to the researches of Dr. Matthews Duncan and M. Robin, even before delivery occurs, so that the muscular tissue of the Uterus is never left completely denuded.†

752. As to the reason why the period of Parturition should be just forty weeks after the occurrence of Conception, we know nothing more than we do of that of similar *periodical* phenomena in the history of the life of Man and of other living beings; all of which must be considered

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* In addition to the evidence above referred-to, of the rapid occurrence of fatty degeneration of the uterine structure after parturition, the Author may mention that he has been informed by Dr. Retzius (Professor of Midwifery at Stockholm) that he has detected a large number of fat-globules in the urine of puerperal women. Is it not possible—it may be further asked—that some of the oleaginous matter so copiously poured-forth by the Mammary glands, may be derived from this source? Such an economy of nutrient material would be consistent with what we elsewhere meet-with; and the idea is conformable to the fact, that the proportion of butyrine in the milk is much greater in the earlier, than in the later months of lactation.

† See Huxley's "Elements of Comp. Anatomy," 1864, p. 107.

as *occasional* manifestations of changes that are *constantly* in progress, whose rate, being dependent upon the degree of Heat supplied, is so uniform in warm-blooded animals, as to secure a very close conformity to a common standard.* There is evidence that the occurrence of the uterine *nisus* may be induced by a variety of causes, several of which probably concur in the normal act of Parturition. For, in the first place, the state of development of the muscular substance of the Uterus can scarcely be without a considerable influence on this operation. We see it undergoing a gradual augmentation during the period of pregnancy, without any demand being made upon its functional activity; it gradually becomes more and more irritable, contractions being far more readily excited in it by electrical or other stimulation, in the later than in the earlier months of pregnancy; and at last this irritability seems to reach its *acme*, in virtue of the nutritive changes which have been progressively taking place in it, and to discharge itself in one powerful effort. Certain preparatory changes are known to be taking-place in the Uterus itself, during the last two or three weeks of gestation; for its upper part contracts more closely around its contents, as if it were bracing itself up for the coming encounter; whilst there is a greater disposition to relaxation of its lower part, as also in the soft parts surrounding the orifice of the pelvis, so that the whole mass descends. It is well known that there is far less aptitude for dilatation in the os uteri before this change has taken-place; so that premature labours are frequently rendered very difficult and tedious by the resistance which the fœtus encounters from the soft parts, notwithstanding that its smaller size enables it to pass more readily through the pelvic canal.—That the parturient effort, however, is not solely dependent upon the state of development of the uterus, appears from several considerations: and, in the first place, from the very curious fact that, in cases of extra-uterine fœtation, contractions resembling those of labour take-place in its walls. In fact, what may be termed the *maturation* not merely of the Uterus, but also of its Embryonic contents,—a condition analogous to that which precedes the dropping of ripe fruit, and which is acquired by the completion of the developmental process,—appears to have more influence in determining the normal parturient effort, than any other cause which can be assigned. The Placenta of the fully-developed fœtus, indeed, is somewhat in the condition of the footstalk of a ripening fruit; that is, having attained its full evolution as an organ of temporary function, its connection tends to become dissevered in virtue of the further changes which take-place in itself, quite irrespectively of any external agency.† This is very strikingly evinced by the fact, that when the uterus contains two fœtuses, and one of them is expelled,—either in consequence of impeded development or of disease in itself, or because it has attained its own full term of development (as in cases of superfœtation, § 756),—the other, if its development at this period is far from complete, is often retained, and goes-on to its full term, *its* placenta not being detached in the first parturient effort, because it was not then prepared for the separation. It is obvious that this view affords a rational explanation of the occurrence of uterine action in cases of extra-uterine fœtation; for, if the condition of the placental attachment furnish its exciting cause, it will do so equally, whether the placenta be attached to the lining of the uterus, or to that of the Fallopian tube, or to any other organ. It is an additional indication that the immediate stimulus to the parturient effort of the uterus is given by some change in the condition of its fœtal connections, that the term of gestation seems capable of being prolonged by peculiarities in the constitution or rate of development of the fœtus, which are derived from the male parent; for it was ascertained by the late Earl Spencer,* that of 75 cows in calf by a particular bull, the average period was 288½ days, instead of 280; none of these having gone less than 281 days, and two-fifths of them having exceeded 289 days.†

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* This may be best illustrated by the analogy of a Leyden jar which is being charged by the *continuous* action of an Electrical Machine, and which is so arranged as to *discharge* itself spontaneously whenever the disturbance in its equilibrium attains a certain intensity. If the movement of the machine be uniform, and other conditions remain the same, the discharge will take-place at regular intervals.

† Such a change may be easily verified in the Placenta of many of the lower animals, such as the Cat, in which the fœtal and maternal portions remain more distinct from each other, than they do in the Human female; for these become far more easily separable as the period of parturition draws near, than they are at any previous time.

753. Various states of the constitution, especially that which is designated as 'irritability,' may induce the occurrence of the parturient effort at an earlier period; and this constitutes Premature Delivery, or Abortion, according as the child is, or is not, *viable* (§ 754). There are some women in whom this regularly happens at a certain month, so that it seems to be an action natural to them; but it should always be prevented, if possible, being injurious alike to the mother and to the child; and this prevention is to be attempted by rest and tranquillity of mind and body, and by a careful avoidance of all the exciting causes which may produce uterine contractions by their operation on the Nervous system (§ 750). Among the causes of Abortion, however, the death of the fœtus, or an abnormal state of the placental structure, is one of the most common; and thus we have another very distinct proof of the influence which the state of the *contents* of the uterus has on the induction of the parturient effort.

754. The question of the *extreme limits* of the period of Gestation, is

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* See Dr. J. C. Hall, in "Medical Gazette," May 6, 1842.

† The very ingenious doctrine has been propounded by Dr. Tyler Smith ("Parturition, and the Principles and Practice of Obstetrics," London, 1849), that the exciting cause of parturition is to be found in the recurrence of the periodical excitement of the ovary, acting by reflexion on the uterus through the spinal system of nerves, the ovarian nerves being the *excitors*, and the uterine the *motors*; this excitement continuing during the entire period of gestation, and giving a special tendency to abortion at each return; and acting with such potency at the eleventh recurrence, as then to induce the parturient effort. He assigns no other cause, however, why this eleventh recurrence should be so much more effectual than the rest, than that by this time there is a much greater aptitude to contraction in the uterus itself, and an increased readiness to be thrown-off on the part of the placenta,—conditions which seem to the Author to be in themselves adequate to account for the result. Dr. Tyler Smith's hypothesis is distinctly negatived by the following facts:—1. The period of gestation, although *commonly* a multiple of the menstrual interval, is by no means *constantly* so; the former often remaining normal, when the latter is shorter or longer than usual. 2. Parturient efforts take-place in the uterus, notwithstanding the previous removal of the lower part of the spinal cord. 3. The removal of the ovaries in the later part of gestation does not interpose the least check to the parturient action, as Prof. Simpson of Edinburgh has experimentally ascertained.—The Author considers himself fully justified, therefore, in asserting that this hypothesis does not possess the slightest claim to be entertained as even a *possible* one; and would refer, for a more detailed examination of it, to the "Brit. and For. Med.-Chir. Review," vol. iv. p. 1.

one of great importance both to the Practitioner and to the Medical Jurist. —In regard to the *shortest* period at which Gestation may terminate, consistently with the *viability* of the Child, there is still a great degree of uncertainty. Most practitioners are of opinion that it is next to impossible for a fœtus to live and grow to maturity, which has not nearly completed its seventh month; but it is unquestionable that infants born at a much earlier period have lived for some months, or even to adult age. It is rare in such cases, however, that the date of conception can be fixed with sufficient precision to enable a definite statement to be given. Of the importance of the question, a case which some time since occurred in Scotland affords sufficient proof. A vast amount of contradictory evidence was adduced on this trial; but, on the general rule of accepting positive in preference to negative testimony, it seems that we ought to consider it possible that a child may live for some months, which has been born at the conclusion of 24 weeks of gestation. In the case in question, the Presbytery decided in favour of the legitimacy of an infant born alive within 25 weeks after marriage.* A very interesting case is on record,† in which the mother (who had borne five children) was confident that her period of gestation was less than 19 weeks; the facts stated respecting the development of the child are necessarily very imperfect, as it was important to avoid exposing his body, in order that his temperature might be kept-up; but three weeks after his birth, he was only 13 inches in length, and his weight was no more than 29 oz. At that time, according to the calculation of the mother, he might be regarded as corresponding with an infant of 22 weeks or 5 months; but the length and weight were greater than is usual at that period, indicating that he was probably born at about the 25th week. It is an interesting feature in this case, that the calorific power of the infant was so low, that artificial heat was constantly needed to sustain it; but that under the influence of heat of the fire he evidently became weaker, whilst the warmth of a person in bed rendered him lively and comparatively strong. During the first week it was extremely difficult to get him to swallow; and it was nearly a month before he could suck. At the time of the report, he was four months old, and his health appeared very good.—Another case of very early viability has been more recently put on record by Mr. Dodd:‡ in this, as in the former instance, the determination of the child's age rests chiefly on the opinion of the mother; but there appears no reason for suspecting any fallacy. The child seems to have been born at the 26th or 27th week of gestation; and having been placed under judicious management, it has thriven well.—One of the most satisfactory cases on record, is that detailed by Dr. Outrepont§ (Professor of Obstetrics at Wurtzburgh), and stated by Dr. Christison in his evidence on the case first alluded-to. The evidence is as complete as it is possible to be in any case of the kind; being derived not only from the date assigned by the mother to her conception, but also from the structure and history of the child. The gestation could have lasted only 27 weeks, and was very probably less. The length of the child was 13½ inches, and its weight was 24 oz. Its development was altogether slow; and at the age of eleven years, the child seemed no more advanced in body or mind, than most other boys of seven years old. In this last point, there is a very striking correspondence with the results of other observations upon premature children, made at an earlier age.—A very remarkable case has been since put on record by Dr. Barker of Dumfries,* in which the child is affirmed to have been born on the 158th day of gestation, or in the middle of the *twenty-third* week after intercourse. Its size, weight, and grade of development were conformable to the asserted period: for it weighed only 16 oz., and measured 11 inches; it had only rudimentary nails, and scarcely any hair except a little of reddish colour on the back of the head; the eyelids were closed, and did not open until the second day; the skin was shrivelled. When born it was wrapped up in a box and placed before the fire. The child did not suck properly until after the lapse of a month, and did not walk until she was nineteen months old. Three years and a half afterwards this child was in a thriving state, and very healthy, but of small make; she then weighed 29½ lbs.

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* "Report of Proceedings against the Rev. Fergus Jardine," Edinburgh, 1839.

† "Edinb. Med. and Surg. Journal," vol. xi.

‡ "Provincial Medical and Surgical Journal," vol. ii. p. 474.

§ "Henke's Zeitschrift," band vi.

755. A like uncertainty exists with regard to the degree of *protraction* of which the ordinary duration of Gestation is capable.—Many obstetric practitioners, whose experience should give much weight to their opinion, maintain that the regular period of 40 weeks is never extended by more than two or three days; whilst, on the other hand, there are numerous cases on record, which, if testimony is to be believed at all (and in many of these, the character and circumstances of the parties place them above suspicion), furnish ample evidence, that Gestation may be prolonged for at least three weeks beyond the regular term.† In one case, indeed, recorded by Liegard,‡ pregnancy was believed to have lasted 330 days. The English law fixes no precise limit; and the decisions which have been given in our courts, when questions of this kind have been raised, have been mostly formed upon the collateral circumstances. The law of France provides that the legitimacy of a child born within 300 days after the death or departure of the husband shall not be questioned; and a child born after more than 300 days is not declared a bastard, but its legitimacy may be contested. By the Scotch law, a child is not declared a bastard, unless born after the tenth month from the death or departure of the husband.—Very important evidence on this subject is afforded by investigations on the lower animals, which are free from many sources of fallacy that attend human testimony. The observations of Tessier, which were continued during a period of forty years, with every precaution against inaccuracy, have furnished a body of results which seems quite decisive. In the Cow, the ordinary period of gestation is about the same as in the Human female; but out of 577 individuals, no less than 20 calved beyond the 298th day, and of these, some went-on to the 321st, making an excess of nearly six weeks, or about *one-seventh* of the entire period. Of 447 Mares, whose natural period of gestation is about 335 days, 42 foaled between the 359th and the 419th days, the greatest protraction being thus 84 days, or just *one-fourth* of the usual term. Of 912 Sheep, whose natural period is about 151 days, 96 yeaned beyond

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* "Medical Times," Sept. 7 and Oct. 12, 1850.

† A good collection of such cases will be found in Dr. Montgomery's excellent work on the "Signs of Pregnancy," and in Dr. A. Taylor's "Medical Jurisprudence."

‡ "Gaz. des Hôpitaux," 1859.

the 153rd day; and of these, 7 went-on until the 157th day, making an excess of 6 days. Of 161 Rabbits, whose natural period is about 30 days, no fewer than 25 littered between the 32nd and the 35th; the greatest protraction was here *one-sixth* of the whole period, and the proportion in which there was a manifest prolongation was also nearly one-sixth of the total number of individuals. In the incubation of the common Hen, the duration of which must be entirely determined by the rate of embryonic development, Tessier found that there was not unfrequently a prolongation to the amount of three days, or *one-seventh* of the whole period.—In regard to Cows, the observations of Tessier have been confirmed by those of Earl Spencer, who has published* a table of the period of gestation as observed in 764 individuals; he considers the average period to be 284 or 285 days; but no fewer than 310 calved after the 285th day; and of these, 3 went-on to the 306th day, and 1 to the 313th. It is curious that among the calves born between the 290th and 300th days, there was a decided preponderance of males,—these being 74, to 32 females; whilst all of those born after the 300th day were females. The additional series of observations subsequently made by Earl Spencer, in regard to the constant protraction of the period in 75 cows in calf by a particular bull, has been already noticed (§ 752).—Another series of observations has been published by Mr. C. N. Bement of Albany, U.S.,† who has recorded the period of gestation of 62 Cows. The longest period was 336 days; the shortest, 213 days. The average period for male calves was 288 days; and for females 282 days.—On the whole it may be considered, that in regard to the Human female, the French law is a very reasonable one; there being quite sufficient analogical evidence to support the assertions of females of good character, having no motive to deceive, which lead to the conclusion that a protraction of at least four weeks is quite possible, and that a protraction of six weeks is scarcely to be denied.‡

756. There is another question regarding the function of the Female in the Reproductive act, which is of great interest in a scientific point of view, and which may become of importance in Juridical inquiries; namely, the possibility of *Superfœtation*, that is, of two distinct conceptions at an interval of greater or less duration; so that two fœtuses of different ages, the offspring perhaps of different parents, may exist in the uterus at the same time.—The simplest case of Superfœtation, the frequent occurrence of which places it beyond reasonable doubt, is that in which a female has intercourse on the same day with two males of different complexions, and bears twins at the full time; the two infants resembling the two parents respectively. Thus, in the slave-states of America, it is not uncommon for a black woman to bear at the same time a black and a mulatto child; the former being the offspring of her black husband, and the latter of her white paramour. The converse has occasionally, though less frequently, occurred: a white woman bearing at the same time a white and a mulatto child. There is no difficulty in account-

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* "Journal of the English Agricultural Society," 1839.

† "American Journal of the Medical Sciences," October, 1845.

‡ See especially two cases, 183 and 184, detailed by Dr. Murphy in his "Report of the Obstetric Practice of University College Hospital" for 1844; and another case since published by him in the "Medical Gazette" for 1849, vol. xlviii. p. 683.

ing for such facts, when it is remembered that nothing has occurred to prevent the uterus and ovaria from being as ready for the second conception as for the first; since the orifice of the former is not yet closed up; and, at the time when one ovum is matured for fecundation, there are usually more in nearly the same condition.—But it is not easy thus to account for the birth of two children, each apparently mature, at an interval of five or six months; since it might have been supposed that the uterus was so completely occupied with the first ovum, as not to allow of the transmission of the seminal fluid necessary for the fecundation of the second. In cases where two children have been *produced* at the same time, one of which was fully-formed, whilst the other was small and seemingly premature, there is no occasion whatever to imagine that the two were *conceived* at different periods; since the smaller fœtus may have been 'blighted,' and its development retarded, as not unfrequently happens in other cases. Nor is it necessary to infer the occurrence of superfœtation in every case in which a living child has been produced a month or two after the birth of another; since the latter may have been somewhat premature, whilst the former has been carried to the full term. But such a difference can scarcely be, at the most, more than 2½ or 3 months;* and there are several cases now on record, in which the interval was from 110 to 170 days, whilst neither of the children presented any indication of being otherwise than mature.†

757. Whatever be the precise nature and history of the Fecundating process, there can be no doubt that the properties of the Germ depend upon conditions, both material and dynamical, supplied by *both* Parents. This is most obviously shown by the *fusion* of the characters of the parents, which is exhibited by *hybrids* between distinct species or strongly-marked varieties among the lower animals, such as the Horse and Ass, the Lion and Tiger, or the various breeds of Dogs; or in the offspring of parents belonging to two strongly-contrasted Races of Men, such as the European on the one hand, and the Negro or American Indian on the other.—It has long been a prevalent idea that certain parts of the organism of the offspring are derived from the male, and certain other parts from the female parent; and although no universal rule can be laid down upon this point, yet the independent observations which have been made by numerous practical 'breeders' of domestic animals (both mammals and birds), seem to establish that such a *tendency* has a real existence; the characters of the *Animal* portion of the fabric being especially (but not exclusively) derived from the *male* parent, and those of the *Organic* apparatus being in like manner derived from the *female* parent. The former will be chiefly manifested in the external appearance, in the general configuration of the head and limbs, in the organs of the senses (including the skin), and in the locomotive apparatus; whilst the latter show themselves in the size of the body (which is primarily determined by the development of the viscera contained in the trunk), and in the mode in which the vital functions are performed. Thus the

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* For an interesting case of superfœtation, where the difference in the age of the two fœtuses was about three months, see a Report made by Drs. Harley and Tanner to the Obstetrical Society, "Lancet," vol. ii. 1862.

† See the Article 'Superfœtation,' in Dr. Beck's "Elements of Medical Jurisprudence."

mule, which is the produce of the male ass and the mare, is essentially a *modified ass*, having the general configuration of its sire (slightly varied by equine peculiarities), but having the rounder trunk and larger size of its dam; on the other hand, the *hinny*, which is the offspring of the stallion and the she-ass, is essentially a *modified horse*, having the general configuration of the horse (though with a slight admixture of asinine features), but being a much smaller animal than its sire, and thus approaching its dam in size, as well as in the comparative narrowness of its trunk. The influence of the female on the general 'constitution,' and especially on the fattening, milking, and breeding qualities of the offspring, is asserted to be proved by the history of several races of sheep and cattle, which have been most distinguished in these respects.*—But however *general* this rule may prove to be as regards the lower animals, it is by no means *universal;* for instances are by no means unfrequent, in which the multiple progeny of one conception divide between them the characters of the parents in very different modes. Thus, in a case in which a Setter-bitch, having been 'lined' by a Pointer, bore three pups, two of these pups seemed exclusively to resemble the father, appearing to be perfect Pointers in configuration, and growing-up with the habits of that race; whilst the third seemed equally to resemble its mother, being apparently a true Setter both in structure and instinct. Yet notwithstanding this apparent restriction, it subsequently appeared that the pointer-pups must have had something of the setter in their constitution, and the setter-pup something of the pointer. For one of the Pointer-pups (a male) having been matched at the proper age with a Pointer-bitch of pure breed, one of the pups borne by the latter was a *true setter*, exactly resembling its paternal grandmother, and another was *setter-marked;* and the Setter-pup (a female) having been lined by a Setter-dog of pure breed, there were among its litter of pups two *pointers* resembling their maternal grandfather.—The same variety presents itself to even a greater degree in the Human species. For in almost every large family (and sometimes even where there are no more than two children†), it will be observed that the likeness to the father predominates in some of the children, and the resemblance to the mother in others. Still it is rare to meet with instances in which *some* distinctive traits of *both* parents may not be traced in the offspring; these traits often showing themselves in peculiarities of manner and gesture, in tendencies of thought or feeling, in proneness to particular constitutional disorders, &c., even where there is no personal resemblance, and where there has been no possibility that these peculiarities should have been gained by imitation.

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* See Walker "On Intermarriage;" Orton on 'The Physiology of Breeding,' in the "Newcastle Chronicle," March 10, 1854; and Dr. Alex. Harvey 'On the Relative Influence of the Male and Female Parents in the Reproduction of the Animal Species,' in "Edinb. Monthly Journ.," Aug. 1854.

† One of the most remarkable cases of this kind known to the Author, is that of two Sisters, who seem to resemble each other in no one point of configuration or mental character; but of whom one bears a most striking resemblance, both in person and in mind, to her Father; whilst the other no less strikingly resembles her Mother. The only peculiarities which at all indicate their relationship, are a gouty diathesis which they both inherit from their father, and an idiosyncrasy in regard to opium, of which neither is able to take even a small dose (in any form whatever) without violent vomiting.

And even when they are overborne, as it were, in the immediate progeny, by the stronger influence derived from the other side, they will often reappear in a subsequent generation (as in the case just cited), constituting the phenomenon known as *Atavism.*

758. The influence of both Parents on the constitution of the Offspring is strikingly manifested, not merely in the admixture of their characters normally displayed by the latter, but also in the tendency to the *hereditary transmission* of perverted modes of functional activity which may have been habitual to either. The diseases which are usually considered to be most prone thus to reappear in successive generations, are Scrofula, Gout, Syphilis, and Insanity; but it can scarcely be doubted that many others might be added to this list.* The predisposition may have been *congenital* on the part of the parents, or it may have been *acquired* by themselves; and in no case is this more obvious, than in the influence of Alcoholic excesses on the part of one or both parents, in producing Idiocy, a predisposition to Insanity, or weakness and instability of Mind, in the children, this being especially the case where both parents have thus transgressed. Thus out of 359 Idiots, the condition of whose progenitors could be ascertained, it was found that no fewer than 99 were the children of absolute drunkards; and there was reason to believe that a large proportion of the parents of the remainder were more or less intemperate, only about a quarter of the whole number of idiots having been found to be the children of parents who were known to be temperate.† And it is perfectly well known to those who are conversant with Insanity, that of all the 'predisposing causes' of that disorder, habits of intemperance on the part of either or both parents are among the most frequent.—The intensification which almost any kind of perversion of Nutrition derives from being common to *both* parents, is most remarkably evinced by the lamentable results which too frequently accrue from the marriage of individuals nearly related to each other, and partaking of the same 'taint.' Such results must have fallen within the knowledge of almost every one possessing an extended field of observation; but they are brought-out with fearful vividness by the unerring test of properly-collected Statistics. For out of the 359 idiots just referred-to, 17 were *known* to have been the children of parents nearly related by blood; and this relationship was *suspected* to have existed in several other cases, in which positive information could not be obtained. On examining into the history of the 17 families to which these individuals belonged, it was found that they had consisted, in all, of 95 children; that of these no fewer than 44 were idiotic, 12 others were scrofulous and puny, 1 was deaf, and 1 was a dwarf. In some of these families, all the children were either idiotic, or very scrofulous and puny; in one family of 8 children, 5 were idiotic.‡—But it does not seem requisite for the production of

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* See the very interesting and suggestive Chapter 'On Hereditary Disease,' in Sir H. Holland's "Medical Notes and Reflections."

† See Dr. Howe's "Report on Idiocy to the Legislature of Massachusetts," 1848.

‡ See Dr. Howe's Report, p. 90. An abstract of this Report is given in the "Amer. Journ. of Med. Sci.," April, 1849.—The following works may also be referred-to as containing the most recent information upon the important subject of the effects upon the offspring of marriages of consanguinity:—M. Boudin in the "Annales d'Hygiène," vol. xviii. pp. 6–82, who observes that the deaf-mutes of consanguineous origin are from twelve to fifteen times as numerous as they would be if the infirmity were equally distributed

very imperfect offspring from the intermarriage of near relations, that any decided 'taint' should exist in the parents; for the Author's own observations and inquiries lead him to conclude that the same danger results when there is any strong personal or mental 'idiosyncrasy,' such as is often seen to run through the members (both male and female) of a particular family, causing them to be at once recognized as belonging to it, by those who have been familiar with other members.* This liability probably does not exist to nearly the same degree, where the parents, although nearly related, differ widely in physical and in psychical characters, through the predominance of elements which have been introduced by *their* non-related parents; as, for example, when a man strongly resembles his *father* rather than his mother, marries the daughter of his *mother's* brother, who, on her part, resembles her own *mother* rather than her father. But the case previously cited (§ 757) gives warning that even here the 'family idiosyncrasy' may exist in a powerful degree, though in a latent form, and may seriously affect the constitution of the offspring. It is quite as common to meet with Atavism in the transmission of hereditary disease, as in the reproduction of 'family likeness.'

759. Attention has recently been directed to a very curious class of phenomena, which show that where the mother has previously borne offspring, the influence of *its* father may be impressed on her progeny afterwards begotten by a different parent: as in the well-known case of the transmission of Quagga-marks to a succession of colts, both whose parents were of the species Horse, the mare having been once impregnated by a Quagga male;† and in the not unfrequent occurrence of a similar phenomenon in the Human species, as when a widow who marries a second time, bears children strongly resembling her first husband. Some of these cases appear referable to the strong mental impression left by the

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among the offspring of consanguineous and other marriages; Dr. Bemiss in the "Journal of Psychological Medicine" for 1857, p. 368, who supplies facts and arguments against such marriages; Dr. Mitchell in the "Edinb. Med. Journ." for 1862, p. 872, who considers idiocy to be an especially frequent consequence of the marriage of blood-relations, and agrees with M. Boudin in regard to the frequency of deaf-mutism in the offspring; M. Cadiot in the "Comptes Rendus," vol. ii. 1863, p. 978; M. Angelon in idem, vol. i. 1864, p. 166; and Dr. E. Dally in the "Anthropological Review" for May, 1864. Amongst the Editor's own immediate relations there have been five marriages between first-cousins, from which have proceeded thirty-three children; of these eight have died, one from teething, two from croup, and one from hooping-cough (all injudiciously fed), one from accident, one from cyanosis, and two from well-marked scrofulous disease; the last two occurred in the same family, and were the only offspring of an extremely obese father and a highly scrofulous mother. The surviving children are of unusually healthy and fine growth. The Editor therefore, from these and other observations, fully accords with the observations of Dr. G. W. Childs in the "Medico-Chir. Review" for 1862, vol. ii. p. 461, who in criticizing Dr. Bemiss's Essay, remarks that the marriages of blood-relations have no tendency, *per se*, to produce degeneration of race, though they have a tendency to strengthen and develope in the offspring individual peculiarities of the parents, both mental and physical, whether morbid or otherwise.

* A most lamentable instance of this kind, which happened some years ago in a family well known to the Author, was the occasion of his first directing his attention specially to this point. Two first-cousins, possessing a strong 'family idiosyncrasy,' but no definite 'taint,' having married, four children were born, each of which was distinguished by some marked defect of organization or perversion of function; one being deaf and dumb, another scrofulous, a third idiotic, and the fourth epileptic.

† "Philosophical Transactions," 1821.

first male parent upon the female: but there are others which seem to render it more likely that the blood of the female has imbibed from that of the fœtus, through the placental circulation, some of the attributes which the latter has derived from its male parent; and that the female may communicate these, with those proper to herself, to the subsequent offspring of a different male parentage.*—This idea is borne-out by a great number of important facts; and it serves to explain the circumstance well known to practitioners, that secondary syphilis will often appear in a female during gestation or after parturition, who has never had primary symptoms, whilst the father of the child shows no recent syphilitic disorder. For if *he* have communicated a syphilitic taint to the fœtus, the mother may become inoculated with it through her offspring, in the manner just described. As this is a point of great practical importance, it may be hoped that those who have the opportunity of bringing observation to bear upon it, will not omit to do so.

760. There seems good reason to believe, moreover, that the attributes of the Germ are in great degree dependent, not merely upon the *habitual* conditions of the Parents which have furnished its original components, but even upon the condition in which those parents may be at the time of sexual congress. Of this we have a remarkable proof in the phenomenon well known to breeders of animals, that a strong mental impression made upon the female by a particular male, will give the offspring a resemblance to him, even though she has had no sexual intercourse with him;† a circumstance for which there is no difficulty in accounting, on the hypothesis already put-forth regarding the dynamical relation of Mental states to the Organic processes (Chap. xv.). And there is no improbability therefore, in the idea that the offspring of parents ordinarily healthy and temperate, but begotten in a fit of intoxication on both sides, would be likely to suffer permanently from the abrogation of the reason, which they have temporarily brought upon themselves.‡—On the whole, then, we seem entitled to conclude, that the attributes of the embryo will be influenced in a most important degree by the entire condition (as relates both to the organic and the psychical life) of both parents at the time of the sexual congress; and it is probably on account of the perpetual changes taking-place in the bodily and mental state of each individual (his condition at any one time being the general resultant of all those changes), that we almost constantly witness marked differences between children born at successive intervals, however strong may be the 'family likeness' among them; whilst the resemblance between twins is almost invariably much closer.§

761. When it is borne in mind that during the entire period of gestation, the Embryo is deriving its nutriment exclusively from the

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* See an interesting discussion of this question, by Dr. Alex. Harvey, in the "Edinb. Monthly Journ.," Oct. 1849, and Oct. and Nov. 1850; and in his pamphlet "On a Remarkable Effect of Cross-breeding," Edinb., 1851.

† See Harvey, loc. cit.

‡ See a case of this kind related by Mr. G. Combe in the "Phrenological Journal," vol. viii. p. 471.

§ Where twins are very unlike one another, it will usually be found that the dissimilarity is due to the predominance of the characters of the father in one, and of those of the mother in the other; as in the case of the Pointer and Setter previously cited (§ 757).

blood of the Mother, and that the condition of this fluid in relation to her own processes of Nutrition and Secretion, is subject to a very marked influence from her own mental states (Chap. xv.), it cannot fairly be thought improbable, that the developmental processes of the Embryo should be powerfully affected by strong Emotional excitement on her part. Among the facts of this class, there is, perhaps, none more striking than that quoted by Dr. A. Combe* from Baron Percy, as having occurred after the siege of Landau in 1793. In addition to a violent cannonading, which kept the women for some time in a constant state of alarm, the arsenal blew-up with a terrific explosion, which few could hear with unshaken nerves. Out of 92 children born in that district within a few months afterwards, Baron Percy states that 16 died at the instant of birth; 33 languished for from eight to ten months, and then died; 8 became idiotic, and died before the age of five years; and 2 came into the world with numerous fractures of the bones of the limbs, probably caused by irregular uterine contractions. Here, then, is a total of 59 children out of 92, or within a trifle of 2 out of every 3, actually killed through the medium of the Mother's alarm and the natural consequences upon her own organization; an experiment (for such it is to the Physiologist) upon too large a scale for its results to be set down as mere 'coincidences.' —No soundly-judging Physiologist of the present day is likely to fall into the popular error of supposing that 'marks' upon the Infant are to be referred to some *transient* though strong impression upon the imagination of the Mother; but there appear to be a sufficient number of facts on record, to prove that *habitual* mental conditions on the part of the Mother *may* have influence enough, at an early period of gestation, to produce evident bodily deformity, or peculiar tendencies of the mind (§ 715). The error of the vulgar notion on this subject, lies in supposing that *a sudden fright, speedily forgotten*, can exert such a continual influence on the nutrition of the Embryo, as to occasion any personal peculiarity.† The view here stated, is one which ought to have great weight, in making manifest the importance of careful management of the health of the Mother, both corporeal and mental, during the period of pregnancy; since the ultimate constitution of the offspring so much depends upon the influences then operating upon its most impressible structure.

4. *Development of the Embryo.*

762. The history of the evolution of the Germ, from its first appearance as *a single cell* lying in the midst of the yolk, to the time when it presents the form and structure characteristic of its parent-species, and is capable of maintaining an independent existence,—including the details of

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* "On the Management of Infancy," p. 76.

† For some valuable observations on this subject, see Montgomery "On the Signs of Pregnancy."—Numerous cases were recorded a few years since (especially in the "Lancet" and "Provincial Medical Journal"), in which malformations in the Infant appeared distinctly traceable to strong impressions made on the mind of the Mother some months previously to parturition; these impressions having been persistent during the remaining period of pregnancy, and giving rise to a full expectation on the part of the Mother, that the child would be affected in the particular manner which actually occurred. Of one very striking case of this kind, the Author is personally cognizant, it having occurred in the family of a near connection of his own.

the progressive development of each separate organ, from its first appearance as an aggregation of simple cells formed by the duplicative subdivision of the primordial vesicle, to that stage of completeness in which it is able to bear a part in the vital economy of the new being,—and embracing, also, the succession of changes in the provisions for the nutrition of the embryo in the successive phases of its existence, and the adaptations of its general organization to each respectively,—constitutes one of the most interesting departments of Physiological Science, and one which has of late years received a peculiar degree of attention. It is a branch of the inquiry, however, which has, and seems likely to have, less *practical* bearing than any other; for neither as regards the preservation of the body in health, nor its restoration from disease, is it easy to see what direct benefit the most exact knowledge of Embryonic Development is likely to afford. The chief subject on which it throws light, is that of Congenital Malformations and Deficiencies; many of which are now distinctly traceable to *arrest* or *irregularity* of the developmental processes; some of them, indeed, to *excess* (§ 339). For these reasons, the topic before us will be passed-over much more lightly in the present Treatise, than its scientific importance might seem to demand; and all that will be here attempted, will be a mere sketch of the mode in which the evolution of the germ takes-place, this being followed in the first instance as a whole, whilst its principal organs will be afterwards separately considered as they successively present themselves.—This sketch, however, will serve to convey an idea of the nature of the process, and to illustrate its conformity in Man to that great law of progress *from the general to the special*, which is equally manifested in the development of every other organized being.

763. When we first discern the primordial cell which is to evolve itself into the Human organism, we can trace nothing that essentially distinguishes it from that which might give origin to *any* other form of organic structure, either Vegetable or Animal; its condition, in fact, being permanently represented by the humblest single-celled Plants and Animals. The earliest stage of its development consists in simple multiplication by 'duplicative subdivision,' so that a mass of cells comes to be produced, amidst the several components of which no difference can be traced; and this also finds its parallel among the simpler organisms of both kingdoms. Soon, however, this *homogeneous* condition gives rise to a *heterogeneous* one; the further changes which different parts of this mass undergo, not being of the same uniform character, so that a marking-out of *organs*, or instrumental parts adapted for different purposes in the economy, comes to be discernible. The organs whose distinctness first becomes apparent, are not (for the most part) those which we trace in the completed structure, but have a merely temporary character; being evolved either as a sort of scaffolding or frame-work for the building up of the more permanent parts, or with a view to the nutrition of the embryo during the evolution of these. Although the first indications of heterogeneousness in the germinal mass are of nearly the same kind in all animals, —consisting in the formation of a *blastodermic membrane* (composed, however, of nothing else than layers of cells) upon its exterior, which serves as a sort of temporary stomach, whilst a large part of the included mass undergoes liquefaction, and serves as the nutrient material for the

tissues which are to be evolved from it,—yet indications are very speedily manifested, of the *primary division* of the Animal Kingdom of which the new being is a member; thus, in the case of the Human embryo, as of that of all Vertebrated animals, the first outline of the permanent organization is shown in the 'primitive trace' which marks-out the line of the vertebral column (Plate II., Fig. 11); and in this we very soon discern the foundations of the separate vertebræ (Fig. 12, *c*). But there is nothing at this period to distinguish the germ of Man from that of *any other* Vertebrated animal, this early part of the developmental process being carried-on upon the same plan in every member of that sub-kingdom; and it is not until we meet with indications of one of the plans which are peculiar to the respective classes of that sub-kingdom, that we can discover whether the germ in course of evolution is to become a Mammal, Bird, Reptile, or Fish. So, even when it has been recognized as belonging to the Mammalian class, there is at first nothing to distinguish it from that of any other Mammal; and it is only with the advance of the developmental process, that indications successively present themselves, which enable us to distinguish, one after another, the characters of the order, the family, the genus, the species, the variety, the sex, and the individual,—*the more special features progressively evolving themselves out of the more general*, which is the expression of the law of development common to all Organized beings.

764. With this progressive alteration in the condition of the embryo itself, a very remarkable series of alterations is proceeding, *pari passu*, in the mode in which it is supplied with nutrient material, and in the provisions for the aeration of its circulating fluid.—The first evolution of the germ takes-place entirely at the expense of the *yolk*; of which, however, the store contained in the Mammalian ovum is very small. The whole of this is very speedily incorporated in the substance of the germ, by the peculiar process to be presently described; and there is no residual store of 'food-yolk,' such as that which, in the Bird, serves for the nutrition of the embryo during the whole remainder of the developmental process, by being gradually absorbed into the substance of the blastodermic membrane, and there converted into blood. The Mammalian ovum, however, from the time it reaches the Uterus, is furnished with a new supply of nourishment, in the fluid secreted by the Decidual membrane (§ 741); and for the absorption of this, it is particularly adapted by the villosities which develope themselves from its own external envelope. These, at first entirely destitute of blood-vessels, are subsequently penetrated at a certain part of the surface, by the fœtal capillaries brought to them by an organ, the *Allantois*, which is developed in Birds as the temporary instrument of respiration; and thus is originated the *fœtal* portion of the Placenta, of whose formation an account will be presently given (§ 771). From the time that this organ is completed, up to the birth of the Infant, the embryo draws its nutrient materials direct from the maternal blood, though not receiving that blood *as such* into its own organism; and it is through the same medium that the aeration of its own blood is effected, its pulmonary apparatus being as yet inoperative. Its circulating system, arranged in accordance with these requirements, presents many peculiarities which mark its fœtal character; and the alteration in the course of the blood, which takes-

place as soon as the respiratory organs come into play, constitutes the essential difference between intra-uterine and extra-uterine life. If, as sometimes happens, the lungs of the new-born infant expand but imperfectly or scarcely at all, the circulation continues to be carried on in a greater or less degree, upon its intra-uterine plan; and this, when the placenta is no longer capable of supplying the needed aeration, is incompatible with the persistence of life.

765. Our knowledge of the first stages of the developmental process in the Mammalian ovum is in many respects incomplete; and it is requisite to interpret what has been obscurely seen in the ova of this class, by the clearer views derived from observation of those of the lower animals.*—As already stated (§ 739), the germinal vesicle disappears at or about the time of fecundation; but its disappearance is not a result of fecundation, since it also takes-place in the unimpregnated egg, in consequence (it may be presumed) of the completion of its term of life, and of those operations which it was developed to perform. Its place is seen to be occupied, at an early period after fecundation, by a new and peculiar cell, the origin of which is obscure, but the destination of which is most important; for it is by the 'duplicative subdivision' of this cell, first into 2, then into 4, then into 8, and so on, and by the metamorphoses which its progeny undergo, that the whole embryonic fabric is gradually evolved. Hence this cell may be termed the *embryo-cell.*† At the same time, a peculiar change begins to take place in the yolk, the whole sphere of which at first contracts, is then marked-out by a furrow into two hemispheres, and is at last completely divided by the extension of this fission to the centre; each half is again furrowed and then cleft in the same manner, and thus the entire yolk is broken up into a mass of segments (Fig. 170). This 'segmentation' takes place *pari passu* with the multiplication of the embryo-cells, each of which is surrounded by a distinct portion of the yolk; and there seems every probability that it is determined by that multiplication, and that each cell of the pair that is formed by the duplicative subdivision of its predecessor, draws around itself its proper share of the nutritive

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* The researches of Rathke "On the Development of the Snake," 1839, and of the Tortoise, 1848,—of Kölliker ("Müller's Archiv," 1843, p. 68) and Bagge ("De Evolut. Strongyli et Ascarid., Diss. Inaug.," 1841) on the ova of *Entozoa,*—Kölliker's "Entwickelungsgeschichte des Menschen," 1861,—those of v. Bär "On the Development of the Fish," 1835,—those of Mr. Newport ("Philos. Transact.," 1851) and Dugès ("Recherches sur les Batraciens," 1835) on the ova of *Batrachia,*—those of Bischoff ("Entwickelungsgeschichte des Hunde-eies," 1845) on the ova of the *Bitch,*—those of Remak on the Vertebrata ("Untersuch. über die Entwickel. der Wirbelthiere," Berlin, 1855),—of Reichert on the Guinea-pig ("Beiträge zur Entwickelungsgeschichte des Meerschweinchens"), Monatsbericht d. Akad. Berlin, 1860,—of Leuckart contained in Wagner's "Handwörterbuch der Physiologie," art. 'Zeugung,'—of Allen Thomson in the art. 'Ovum,' in the supplementary volume to Todd's "Cyclop. of Anatomy and Physiology," 1859,—of Huxley in the Croonian Lecture for 1858, and in his "Lectures on the Elements of Comparative Anatomy," 1864,—and lastly of Coste ("Histoire Génér. et Partic. du Développement des Corps Organisés," 1847-1859)—are among the most valuable which we at present possess.

† The embryo-cell has not yet been clearly made-out in the Mammalian ovum; but from the conformity of the subsequent appearances to those which are seen in the ova of the lower animals, there is every reason to believe that the formation of either a complete cell, or of a nucleus having the same essential endowments, is a preliminary to the cleavage of the yolk.

material.—These changes take-place, in the Mammalian Ovum, during its transit along the Fallopian tube to the uterus; so that, by the time of its arrival there, the whole cavity of the *Zona pellucida* is occupied by minute spherules of yolk, each containing a transparent vesicle,* the aggregation of which gives it a mulberry-like aspect (Fig. 171, A); and by a continuance of the same process of subdivision, the component segments becoming more and more minute, the mass comes to present a finely-granular aspect (B). A rotation of the yolk at this period was observed by Dr. Ransom in the ova of the Gasterosteus, and was soon after noticed in the Pike by Reichert, in the Frog by Ecker, and subsequently in the Rabbit and Guinea-pig by Bischoff. The cause of this singular movement is still unknown, and though Bischoff stated that he had seen cilia in the rabbit on the outer surface of the yolk, he was unable to satisfy himself of their presence in the guinea-pig.

FIG. 170.

A B C

Progressive stages in the *Segmentation of the Yolk* of the Mammalian Ovum:—A, its first division into two halves; B, subdivision of each half into two; C, further subdivision, producing numerous segments.

FIG. 171.

A B

Later stage in the *Segmentation of the Yolk* of the Mammalian Ovum:—at A is shown the 'mulberry-mass' formed by the minute subdivision of the vitelline spheres; at B, a further increase has brought its surface into contact with the vitelline membrane, against which the spherules are flattened.

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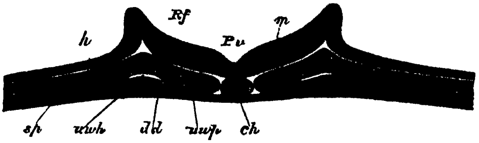
* It is by no means certain that this vesicle is a true cell in the Mammalian ovum (as it seems clearly to be in the ovum of many of the lower animals), its appearance, when liberated from the yolk-granules which surround it, being rather that of a fat-, or oil-globule.

766. At this stage, it does not appear that the several segments of the yolk have a distinct enveloping membrane; but an envelope is now formed around each of them, converting it into a cell, of which the included vesicle constitutes the nucleus, and of which the portion of the yolk surrounding this forms the contents. This happens first to the peripheral portions of the mass; and as its cells are fully developed, they arrange themselves at the surface of the yolk into a kind of membrane, and at the same time assume a pentagonal or hexagonal shape from mutual pressure, so as to resemble pavement-epithelium (Plate I., Fig. 5). As the globular masses of the interior are gradually converted into cells, they also pass to the surface and accumulate there, thus increasing the thickness of the membrane already formed by the more superficial layer of cells, while the central part of the mass remains occupied only by a clear fluid. By this means the exterior of the yolk is speedily converted into a kind of secondary vesicle, situated within the Zona pellucida, and named by Bischoff the *blastodermic vesicle.* This vesicle, very soon after its formation, presents at one point an opaque, at first hemispherical, but subsequently discoid mass (Plate I., Fig. 5), which is produced by an accumulation of the original segmentary spheres that have not yet been developed into cells like the rest of the yolk mass. The blastodermic vesicle increases rapidly in size, and becomes filled with fluid furnished by the uterus. When it has attained to $\frac{3}{4}'''$ in the ovum of the Rabbit, a round spot begins to be distinguished by its white opaque appearance; this is the Area germinativa (Plate I., Fig. 6). The Area germinativa continually increases in extent and thickness by the formation of new cells; and subdivides into layers (Plate I., Fig. 7), which, although both at first composed of cells, soon present distinctive characters, and are concerned in very different ulterior operations. Whilst this is progressing the fine membrane covering and enclosing the blastodermic vesicle begins to show small mammillary eminences, whence the name which has been suggested for this membrane, of *Chorion primitivum* or *Membrana ovi externa.* The ovum at this period, therefore, consists of the external villous membrane or primitive chorion; of the blastodermic vesicle, composed of two layers; and of the cellular yolk. The division of the blastodermic vesicle into two layers, is at first most evident in the neighbourhood of the *Area germinativa;* but it soon extends from this point and implicates nearly the whole of the germinal membrane. The outer, or as it has sometimes been termed, the *serous* layer of the blastodermic vesicle, remains single, but the inner or *mucous* layer soon subdivides into two other laminæ, of which the more external (*sp*, Fig. 172) is composed of several strata, whilst the internal (*dd*) resembles an epithelium, and is called the glandular layer.

767. The Area Germinativa at its first appearance has a rounded form; but it soon loses this, first becoming oval, and then pear-shaped (Plate II., Fig. 11). While this change is taking-place in it, there gradually appears in its centre a clear space, termed the *area pellucida* (*a*); and this is bounded externally by a more opaque circle, whose opacity is due to the greater accumulation of cells and nuclei in that part than in the area pellucida. The first appearance of the embryonic structure, known as the *primitive trace*, consists in a shallow groove (*c*, Plate II., Fig. 11, and *Pv*, Fig. 172), lying between two masses (*b*, Plate II., Fig. 11, and *Rf* and *m*, Fig. 172), known as the *laminæ dorsales*, whose form

changes with that of the area pellucida, being at first oval, then pyriform, and at last becoming guitar-shaped; they also rise more and more from the surface of the area pellucida, so as to form two ridges of higher elevation, with a deeper groove between them; and the summits of these ridges tend to approach each other, and gradually unite from before backwards, so as to convert the groove into a tube. At the same time, the anterior portion of the groove dilates into three recesses or vesicles (Plate II., Fig. 12, *b*), which indicate the position of the three principal divisions of the Encephalon, afterwards to be developed as the *prosencephalon*, the *mesencephalon*, and the *epencephalon* (§ 789). Of the three blastodermic layers, the upper or external one (*h*) furnishes by its median portion (*Rf*, *m*), the central parts of the nervous system, together with the higher organs of sense—sight, hearing, and smell; and by its lateral portion (*h*), which Kölliker calls the corneal layer (hornblatt), the epidermis and all epidermic tissues. From the innermost layer, *dd*, the epithelial layers of the intestinal tube and of all the glands connected with it are developed; whilst the middle layer, *sp*, at first simple, soon becomes divided into several strata, in which the bones, the muscles, the generative organs, and all vascular parts with the exception of the central nervous system, are developed.

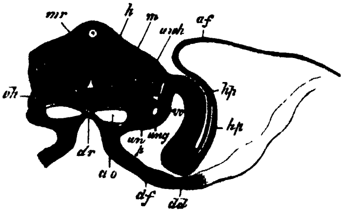
FIG. 172.



Transverse section through the *Embryo of the Chick* at the close of the first day of incubation, magnified about 100 diameters:—*ch*, chorda dorsalis; *h*, external serous or corneal layer; *m*, medullary portion of serous layer; *Pv*, primitive groove between the dorsal laminæ *Rf* and *m*; *dd*, intestinal epithelial or glandular layer (mucous layer); *uwp*, prevertebral mass, in which the primary or protovertebræ are formed, and which is continuous with the middle lamina, *sp*; *uwh*, fissure in the middle lamina, presenting the first indication of the pleuro-peritoneal cavity, and of the subsequent division of the middle lamina into two layers.

768. Before these new structures are produced, a very remarkable change takes-place in that part of the blastodermic vesicle which surrounds the area pellucida, the corneal or outermost lamina (*af*, Fig. 173), uniting with a portion of the middle parietal layer (*hp*), and rising up on either side in two folds (Fig. 176, *d*, *e*); these gradually approach one another, and ultimately meet in the space between the general envelope and the embryo, thus affording an additional investment to the latter (Fig. 174). As each fold contains two layers of membrane, the investment thus formed is double; of this, the outer lamina adheres to the general envelope; whilst the inner remains as a distinct sac, to which the name of *Amnion* is given. This takes-place during the third day in the Chick; the date at which it

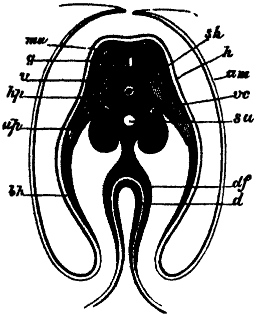
FIG. 173.



Transverse section of the *Embryo of Fowl* at the beginning of [illegible] incubation × 90—100: — *ch*, chorda dorsalis; *uwh*, position of a thinning or cavity in the protovertebral mass, dividing it into an anterior and posterior portion; *hp*, parietal lamina; *df*, intestinal fibrous lamina; *dd*, intestinal glandular lamina; *dr*, primitive intestinal groove; *h*, corneal lamina, (the line in the drawing extending a little too far); *mr*, medullary tube (spinal cord); *m*, muscular lamina; *p*, pleuro-peritoneal cavity; *af*, fold of the amnios; *ao*, primitive aorta; *vc*, vena cardinalis; *un*, Wolffian body; *ung*, duct of the Wolffian body.

occurs in the Human ovum is difficult to be ascertained, owing to the small number of normal specimens which have come under observation at a sufficiently early stage. A microscopic examination of the Amniotic membrane in the Human subject shows that it consists of an inner layer of tesselated epithelium, and an outer layer, which even at the fourth week presents spindle-formed corpuscles, and at the seventh week has become well-marked connective tissue. In some animals it is provided with muscular fibres, and performs distinct movements; but it never in any species possesses proper vessels. The Amnion is directly continuous with the skin of the embryo.

Fig. 174.



Transverse section made through the body of the *Embryonic Fowl*, near the umbilicus on the fifth day of incubation:—*sh*, sheath of the chorda; *h*, corneal lamina; *am*, amnios completely closed; *sa*, secondary aorta; *vc*, *venæ cardinalis*; *mo*, muscular lamina; *g*, spinal ganglion; *v*, anterior root of the spinal nerve; *hp*, parietal lamina; *up*, prolongation of the protovertebra into the abdominal wall (protovertebral lamina of Remak, visceral lamina of Reichert); *bh*, primitive wall of the abdomen, composed of the external, serous, or corneal lamina, and of the parietal lamina; *df*, lamina in which the fibrous membranes of the intestines are developed; *d*, intestinal glandular layer. The mass around the chorda is that in which the protovertebræ are developed; it contains the vessels anteriorly, and in front, in the middle line, is prolonged as the mesentery.

769. As the development of the embryo progresses, the walls of the abdomen and the coats of the intestines begin to be formed by the bending downwards and forwards of the lateral portions of the blastodermic vesicle. In Fig. 174, the mode of development of the abdominal cavity is seen, its parietes being formed by the external or parietal portion of the middle laminæ (*hp*), whilst within it the deep groove of the intestines (*d*) appears, the walls of which are composed of two laminæ, the intestinal fibrous lamina (*df*), and the intestinal glandular layer (*d*), passing into the corresponding laminæ of the blastodermic vesicle, which already form the vitelline sac. The incipient intestine is maintained in its place by the mesentery, which begins to be formed out of a prolongation of the mass lying in front of the chorda dorsalis, in which lie the now unsymmetrical aorta (*sa*) and the cardinal vein (*vc*), and which is obviously only a thickened portion of the connecting band between the parietal lamina and the intestinal fibrous layer (*mp*, Fig. 190)——During the same period, a very important provision for the future support of the embryo begins to be made, by the development of Blood-vessels and the formation of Blood. Hitherto, the embryonic structure has been nourished by direct absorption of the alimentary materials supplied to it by the yolk; but its increasing size, and the necessity for a more free communication between its parts than any structure consisting of cells alone can permit, call for the development of *vessels* through which the nutritious fluid may be conveyed. These vessels are first seen in that part of the Vascular lamina of the germinal membrane, which immediately surrounds the embryo. In their earliest stage of development these vessels appear as *two arcus aortæ*, proceeding from the anterior part of the heart, that, after a short course in the forward direction, bend downwards and backwards to unite in a single, short, unsymmetrical aortic tube, from which again two branches almost imme-

diately arise, the *arteriæ vertebrales posteriores*, or primitive aortæ. These, lying beneath the chorda dorsalis, extend to the posterior part of the body of the embryo, dividing ultimately into the omphalo-mesenteric, meseraic, or Vitelline vessels (Figs. 181, 182, *q*, *r*), which form a close network, bounded by a circular channel termed the *Vena* or *Sinus terminalis*. This network or vascular area (Plate II., Fig. 13) soon extends itself, and the vessels finally spread over the whole of the membrane that contains the yolk. At the anterior part of the embryo the two extremities of the circular channel form the Venæ *omphalo-mesentericæ*, which discharge their contents into the back part of the heart.—At this period the Yolk-sac is entirely separated in the Mammalia, by a constriction of the portion which is continuous with the abdomen of the embryo (Fig. 180, *b*); and it is known from that time under the name of the *Umbilical Vesicle* (Plate I., Fig. 10, *i*). The communication, however, remains open for a time through the 'vitelline duct;' and even after this has been cut-off, the trunks which connect the circulating system of the embryo with that of the vascular area are discernible. The two first veins, then, that are developed, are the Venæ omphalo-mesentericæ, which belong not to the body of the embryo itself, but to the germinal area, and open by a short tube common to both into the posterior extremity of the Heart (Fig. 177, 1, *om*). Subsequently by the extension of their branches over the yolk-sac they become the vitelline vessels, still opening by two veins into the heart. With the formation of the intestine, however, the vessel of the right side disappears, the left alone remaining (Fig. 177, 2, *om''*), which is soon joined by a small mesenteric vessel from the intestine (Fig. 177, 3, *m*). Before this is accomplished, however, the Allantois has been developed, from which two Venæ umbilicales pass forwards and open into the common trunk of the Venæ omphalo-mesentericæ (Fig. 177, 1, *u'u''*).. The Venæ umbilicales rapidly increase in size, preponderating so much over the only remaining Venæ omphalo-mesenterica, into which they originally discharged their contents, that the latter now appears to be merely a tributary branch. As the Liver becomes developed it surrounds the trunk of the umbilical vein (Fig. 177, 3), which soon forms a twofold system

FIG. 175.

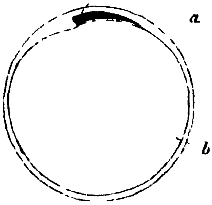


FIG. 176.

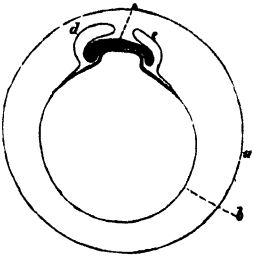


Fig. 175.—Plan of early *Uterine Ovum*. Within the external ring, or zona pellucida, are the serous lamina, *a*; the yolk, *b*; and the incipient embryo, *c*.

Fig. 176.—Diagram of Ovum at the commencement of the formation of the *Amnion*:—*a*, chorion; *b*, yolk-sac; *c*, embryo; *d*, and *e*, folds of the serous layer rising-up to form the amnion.

of tubes within that gland, the one conveying the blood to the liver, the Venæ hepaticæ advehentes; the others return the blood from the gland substance to the umbilical vein again, constituting the Venæ hepaticæ revehentes. The right umbilical vein now disappears, and the blood returning from the placenta altogether traverses the left vein, which soon takes up a median position; the remains of the omphalo-mesenteric vessel (*om*, Fig. 177, 4), together with branches (*m*) derived from the intestine, ultimately come to open into the right *Vena hepatica advehens* of the umbilical vein, and thus constitute the origin of the portal vein. That portion of the umbilical vein which lies between the two systems of hepatic branches just mentioned, remains throughout the whole of fœtal life, and is termed the Ductus venosus Arantii. It was formerly believed that the nutrient matter of the yolk passes directly through the vitelline duct, into the (future) digestive cavity of the embryo, and is from it absorbed into its structure; but there can now be little doubt, that the vitelline vessels are the real agents of its absorption, and that they convey it through the general circulating system, to the tissues in process of formation. They correspond, in fact, to the Mesenteric veins of Invertebrated animals, which are the sole agents in the absorption of nutriment from their digestive cavity; and the blastodermic vesicle is to be regarded as the temporary stomach of the embryo,—remaining as the permanent stomach in the Radiated tribes.*

FIG. 177.

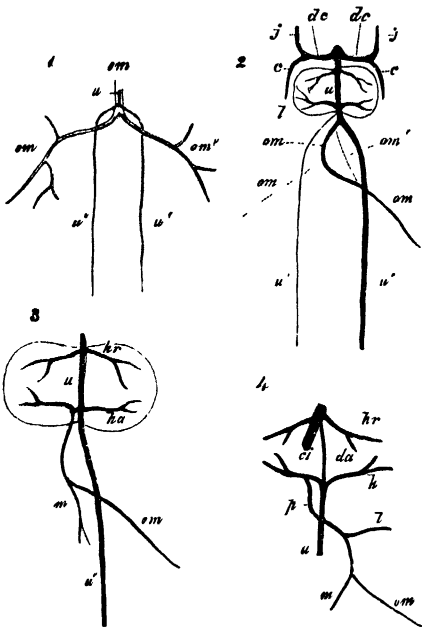


Diagram of the formation of the *Venæ Omphalo-mesentericæ* and *Umbilicales*:—1. At the time of the first appearance of the umbilicales and the commencement of the omphalo-mesentericæ. 2. At the time of the first appearance of the branches to and from the liver, and the diminution of the omphalo-mesenteric vessels. 3, 4. At the period of complete fœtal circulation in 1, omphalo-mesenteric trunk; in 2, 3, remains of it; in 4, vein of the yolk-sac alone; *om'* right and *om''* left vena omphalo-mesentericæ; *u*, trunk of the umbilical vein; *u'* right and *u''* left vena umbilicalis; *dc*, ductus Cuvieri; *j*, jugularis; *c*, cardinalis; *l*, liver; *ha*, hepaticæ advehentes; *hr*, hepaticæ revehentes; *m*, mesentericæ; *da*, ductus venosus Arantii; *ci*, cava inferior; *p*, vena portæ; *l*, lienalis; *m*, mesenterica superior.

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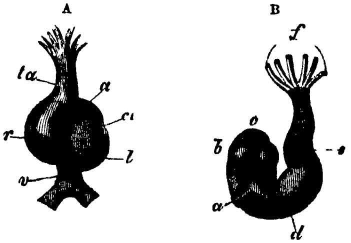
* Previously to the ninth day of incubation (in the Fowl's egg), a series of folds are formed by the lining membrane of the yolk-bag, which project into its cavity; these become gradually deeper and more crowded, as the bag diminishes in size by the absorption of its contents. The vitelline vessels that ramify upon the yolk-bag, send into these folds (or valvulæ conniventes) a series of inosculating loops, which immensely increase the extent of this absorbing apparatus. But these minute vessels are not in immediate contact with the yolk; for there intervenes between them (as was first noticed by Mr.

770. The first rudiment of the *Heart*, which is the earliest of the permanent organs of the embryo that comes into functional activity, consists of an aggregation of cells, forming a thickening of the fibrous coat of the anterior portion of the intestinal canal; the innermost cells of which becoming detached, float in the newly-formed cavity as the first blood-corpuscles, whilst the outer remain to constitute its walls. For a long time after it has distinctly commenced pulsating, and is obviously exerting a contractile force, its walls obviously retain the cellular character, and only become muscular by a progressive histological transformation. The first appearance of the Heart in the Chick is at about the 27th hour; the time of its formation in Mammalia has not been distinctly ascertained. In its earliest form, it has the same simple character which is presented by the central impelling cavity of the lower Invertebrata; being a mere prolonged canal, which at its posterior extremity receives the veins, and at its anterior sends-forth the arteries. About the 15-18th day in the Human Embryo it becomes doubly bent upon itself (Plate II., Fig. 13, *d*, and Fig. 178, A, B), one loop corresponding to the arterial, the other to the venous portion. After this, two slight enlargements (*b*) are observed in the venous bend; and the arterial bend separates into two parts by a long line of division. The two enlargements represent the auricles, and receive the venæ omphalo-mesentericæ (*a*). Above, they open into the atrium (*c*), which leads to the right ventricle (*d*), and this again into the bulbus aortæ. The circulation is at first carried-on exactly upon the plan which is permanently exhibited by Fishes. The Aorta subdivides on either side of the neck into five or six arches (Figs. 181, 182, *e*, *e'*, *e''*), which are separated by fissures much resembling those forming the entrances to the gill-cavities of Cartilaginous Fishes; and these arches re-unite to form the descending aorta, which transmits branches to all parts of the body.—Such is the first phase or aspect of the Circulating Apparatus, which is *common to all Vertebrata* during the earliest period of their development, and which may, therefore, be considered as its most general form. It remains permanent in the class of Fishes; and in them the vascular system undergoes further development on the same type, a number of minute tufts being sent-forth from each of the arches, which enter the filaments of the gills, and are thus subservient to the aeration of the blood. In

FIG. 178.



A. Heart of the *Embryo of a Rabbit* seen from before:—*ta*, truncus arteriosus; *l*, left ventricle; *r*, right ventricle; *a*, auricle; *v*, venous sinus.

B. The same heart seen from behind:—*a*, venæ omphalo-mesentericæ; *d*, right auricle; *e*, bulbus aortæ; *f*, the six aortic arches; *c*, atrium; *b*, auriculæ.

Dalrymple) a layer of nucleated cells, which is easily washed away. (See Dr. Baly's Translation of "Müller's Physiology," pp. 1557–1559.) It was from the colour of these, communicated to the vessels beneath, that Haller termed the latter *vasa lutea;* when the layer is removed, the vessels present their usual colour. There seems good reason to believe that these cells, like those of the Intestinal Villi in the adult (§ 106), are the real agents in the process of absorbing and assimilating the nutritive matter of the yolk; and that they deliver this up to the vessels, by themselves undergoing rupture or dissolution, being replaced by new layers.

higher Vertebrata, however, the plan of the circulation is afterwards entirely changed, as will be presently described, by the formation of new cavities in the heart, and by the production of new vessels; it is incorrect, therefore, to speak of the vascular arches in *their* necks as *branchial* arches, since no branchiæ or gills are ever developed from them. The clefts between them may be very distinctly seen in the Human Fœtus towards the end of the first month; during the second, they usually close-up and disappear.

771. With the evolution of a Circulating apparatus, adapted to absorb nourishment from the store prepared for the use of the Embryo, and to convey it to its different tissues, it becomes necessary that a Respiratory apparatus should also be provided, for depurating the blood from the carbonic acid with which it becomes charged during the course of its circulation. The temporary Respiratory apparatus now to be described, bears a strong resemblance in its own character, and especially in its vascular connections, to the gills of the Mollusca; which are prolongations of the external surface (usually near the termination of the intestinal canal), and which almost invariably receive their vessels from that part of the system. This apparatus, which is termed the *Allantois*, sprouts-forth from the anterior and lower part of the wall of the belly of the embryo, at first as a little mass of cells, which soon exhibits a cavity (probably originating in the liquefaction of the cells of the internal part), so that a vesicle is formed (Figs. 179, 180, *g*), which looks like a diverticulum from the lower part of the digestive cavity. This vesicle, in Birds, has been shown by Vulpian* to be possessed of a distinct contractile power, and soon becomes so large as to extend itself around the whole yolk-sac, intervening between it and the membrane of the shell, and coming through the latter into relation with the external air; but in the embryo of Mam-

FIG. 179.

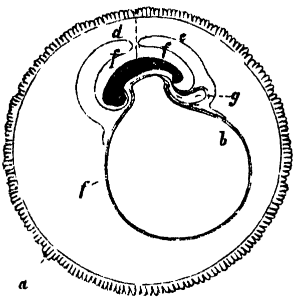


FIG. 180.

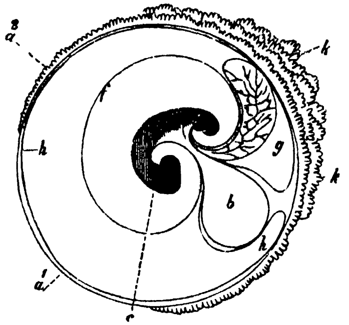


Fig. 179.—Diagram of an early *Human Ovum*, showing the *Amnion* in process of formation and the *Allantois* beginning to appear:—*a*, chorion; *b*, vitelline mass surrounded by the blastodermic vesicle; *c*, embryo; *d*, *e*, and *f*, external and internal folds of the serous layer, forming the amnion; *g*, incipient allantois.

Fig. 180.—Diagram of a *Human Ovum* in second month, showing the completion of the sac of the *Amnion*, and a further development of the *Allantois*:—*a* 1, smooth portion of chorion; *a* 2, villous portion of chorion; *k*, *k*, elongated villi, beginning to collect into Placenta; *b*, vitelline or umbilical vesicle; *c*, embryo; *f*, amnion (inner layer); *g*, allantois; *h*, outer layer of amnion, coalescing with chorion.

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* "Journ. de la Physiologie," tom. i. p. 619 *et seq.*

malia, the allantois, being early superseded by another provision for the aeration of the blood, seldom attains any considerable dimensions. Its chief office here is to convey the vessels of the embryo to the Chorion; and its extent bears a pretty close correspondence with the extent of surface through which the Chorion comes into vascular connection with the decidua. Thus, in the Carnivora, whose placenta extends like a band around the whole ovum, the allantois also lines nearly the whole inner surface of the chorion; on the other hand, in Man and the Quadrumana, whose placenta is restricted to one spot, the allantois is small, and conveys the fœtal vessels to one portion only of the chorion. When these vessels have reached the chorion, they ramify in its substance, and send filaments into its villi; and in proportion as these villi form that connection with the uterine structure which has been already described (§§ 744, 745), do the vessels increase in size. They then pass directly from the fœtus to the chorion; and the allantois, being no longer of any use, shrivels-up, and remains as a minute vesicle only to be detected by careful examination. The same thing happens in regard to the umbilical vesicle, from which the entire contents have been by this time withdrawn; and from henceforth the fœtus is completely dependent for the materials of its growth upon the supply it receives through the Placenta, which is conducted to it by the vessels of the umbilical cord. This state of things is represented in Figs. 181, 182, *n n′*, *o o′*.—The Allantois is commonly said to give origin to the Urinary Bladder; but this organ is really formed by an enlargement of the upper part of the uro-genital sinus (§ 781), with which the allantois communicates by a duct which gradually shrivels, only a vestige of it remaining permanent, to form the Urachus or suspensory ligament of the bladder, by which this is connected with the umbilicus. Before this takes-place, however, the Allantois is the receptacle for the secretion of the Corpora Wolffiana, and also for that of the true Kidneys, when they are formed (§ 779).

772. It will be seen from the succeeding diagram, that the Amnion forms a kind of tubular sheath around the umbilical cord; it is continuous at the umbilicus with the integument of the fœtus; and at the point where the cord enters the placenta, it is reflected over its internal or fœtal surface. It thus forms a shut sac, resembling that of the pleura, arachnoid, &c.; and it contains a fluid, known as the *liquor amnii*, which consists of water holding in solution a small quantity of albumen and saline matter, and resembling, therefore, very diluted serum. During the first two months of gestation, the amnion and the inner lining of the chorion (which is really the reflected layer of the amnion, Fig. 180, *h*, just as the lining of the abdominal cavity is formed by the peritoneum) are separated by a gelatinous-looking substance; which probably aids in the nutrition of the embryo, previously to the formation of the placenta. This is absorbed during the second month; and the amnion is then found immediately beneath the chorion.—In the Umbilical Cord, when it is completely formed, the following parts may be traced. 1. The tubular sheath afforded by the Amnion. 2. The Umbilical Vesicle (Fig. 181, *t*) with its pedicle, or vitelline duct. 3. The Vasa Omphalo-Meseraica (*q*, *r*), or mesenteric vessels of the embryo, by which the yolk was absorbed into its body; these accompany the pedicle. 4. The Urachus, and remains of the Allantois. 5. The Vasa Umbilicalia (*n n*, *o*), which, in the later

period of gestation, constitute the chief part of the Cord. These last vessels consist in Man of two arteries and one vein. The arteries are the main branches of the Hypogastric; and they convey to the placenta the blood which has to be aerated and otherwise revivified, by being brought into relation with that of the mother. The vein returns this to the fœtus, and discharges a part of it into the Vena Portæ, and a part directly through the Ductus Venosus into the Vena Cava.

FIG. 181.

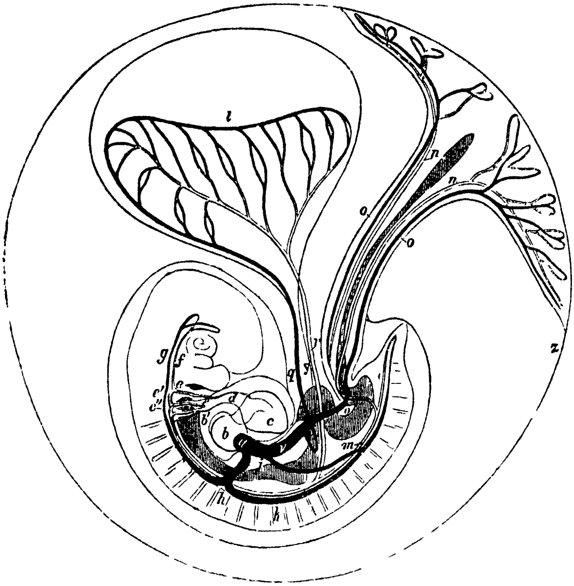


FIG. 182.

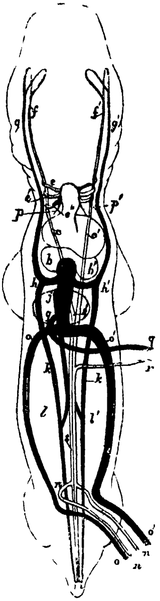


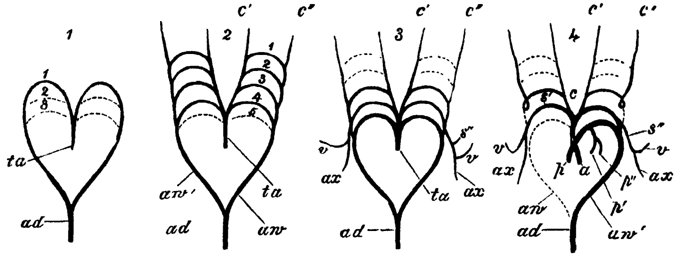
Fig. 181.—Diagram of the Circulation in the *Human Embryo* and its Appendages, as seen in profile from the right side, at the commencement of the formation of the Placenta.

Fig. 182.—The same, as seen from the front:—*a*, venous sinus, receiving all the systemic veins; *b*, right auricle; *b'*, left auricle; *c*, right ventricle; *c'*, left ventricle; *d*, bulbus aorticus, subdividing into *e*, *e'*, *e''*, branchial arches; *f*, *f'*, arterial trunks formed by their confluence; *g*, *g'*, vena azygos superior; *h*, *h'*, confluence of the superior and inferior azygos; *j*, vena cava inferior; *k*, *k'*, vena azygos inferior; *m*, descending aorta; *n*, *n*, umbilical arteries proceeding from it; *o'*, *o*, umbilical veins; *q*, omphalo-mesenteric vein; *r*, omphalo-mesenteric artery, distributed on the walls of the vitelline vesicle, *t*; *v*, ductus venosus; *y*, vitelline duct; *z*, chorion.

773. A change in the type of the Circulating system of the fœtus, from that at first presented by it (§ 769), takes-place at a very early period. Between the fourth and eighth week the venous portion of the heart becomes much enlarged, and a septum begins to be formed which gradually divides the single ventricular cavity into two, the separation being completed at the seventh week. The septum of the auricles commences in the eighth week, but remains incomplete throughout the whole of fœtal life, the opening being termed the foramen ovale. Contemporaneously with the formation of these septa, a transformation occurs in the arrangement of the Arterial trunks proceeding from the heart, which ends in their assumption of the form they present until the end of Fœtal life; and this undergoes but a slight alteration, when the plan of the circulation is

changed at the moment of the first inspiration. The number of aortic arches on each side, which was five at first, soon becomes reduced in the Mammalia to three, by the obliteration of the two highest pairs. The Bulbus Aorticus is subdivided by the adhesion of its walls at opposite points into two tubes, of which one becomes the origin of the aorta, and the other that of the pulmonary artery, and of the three remaining pairs of vascular (branchial) arches; the third being connected with the aortic trunk, contributes, with portions of the two highest pairs, to the formation of the external and internal carotid arteries; whilst of the second pair, the arch on the right side forms the innominate and the beginning of the right subclavian, and the other becomes the arch of the aorta, and contributes to form the left subclavian. The lowest pair is entirely obliterated on the right side. On the left it gives-off the pulmonary artery, and remains throughout fœtal life, in communication with the aorta, as the Ductus Arteriosus.[*]—A knowledge of these different stages in the development of the Heart and Arterial system enables us to explain many of the malformations which they occasionally present in Man; these being for the most part due to arrest of development, whereby the circulating apparatus is permanently fixed in conditions that are properly characteristic of cold-blooded animals. And it is interesting to remark, too, that the varieties which not unfrequently present themselves in the arrangement of the principal trunks given-off from the Aorta, find their analogues in the arrangements that are normally characteristic of some or other of the Mammalia.

FIG. 183.



1. *Truncus arteriosus* with one pair of aortic arches, and dotted outlines indicating the future position of the second and third pairs. 2. *Truncus arteriosus* with four pairs of aortic arches and indications of the fifth. 3. *Truncus arteriosus* with the three posterior pairs of aortic arches, from which the permanent vessels of the embryo are developed, with dotted outlines showing the position of the two (now) obliterated anterior arches. 4. Permanent arterial trunks in their primitive form, the obliterated portions still shown in dotted outline. 1—5, primitive aortic arches; *a*, aorta; *p*, pulmonary artery; *p'*, *p''*, branches to the lungs; *aw'*, root of thoracic aorta (*ad*) on left side; *aw*, obliterated root springing from right side; *s' s''*, subclavian artery; *v*, vertebral; *ax*, axillary; *c*, common carotid; *c'*, external carotid; *c''*, internal carotid.

774. The *Venous* system of the body generally, undergoes changes which are even more remarkable than those of the arterial trunks. In its earliest condition, it has been ascertained by Rathke[†] to present essentially the same type in the embryoes of all Vertebrated animals; the peculiarities of each group being acquired by a process of subsequent transformation. There is at first a pair of anterior venous trunks (Figs. 181, 182, *g*, *g'*), receiving the blood from the head, and a pair of posterior trunks (*k*, *k'*),

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[*] Kölliker, "Entwickelungsgeschichte des Menschen," p. 409.

[†] "Ueber den Bau und die Entwickelung des Venensystems der Wirbelthiere," 1838.

formed by the confluence of the veins of the trunk, of the Wolffian bodies, &c.; the former are persistent as the jugular veins; the latter remain separate in most Fishes, where they are designated the cardinal veins; but in Man (as in warm-blooded Vertebrata generally), they are only represented by the *venæ azygos*, major and minor,* which coalesce into a common trunk for a considerable part of their length. One of the anterior trunks and one of the posterior unite on either side, to form a canal which is known as the Ductus Cuvieri; and the ducts of the two sides coalesce to form a shorter main canal, which enters the auricle, at that time an undivided cavity. This common canal is absorbed into the auricle at an early period, in all Vertebrata above Fishes; and after the septum auriculorum is formed, the two Cuvierian ducts separately enter the right auricle. This arrangement is persistent in Birds and the inferior Mammals, in which we find two Venæ Cavæ superiores, entering the right auricle separately; but in the higher Mammalia and in Man, the left duct is obliterated, and the right alone remains as the single Vena Cava superior, a transverse communicating branch being formed, to bring to it the blood of the left side.† The double Vena Cava sometimes presents itself as a monstrosity in the Human subject. As the anterior extremities are developed, the subclavian veins are formed to return the blood from them; and these discharge themselves into the jugulars. The Omphalo-Mesenteric vein (Fig. 181, *q*), which has been already (§ 769) shown to be formed by the confluence of the veins of the yolk-bag and intestinal canal, passes by itself, with the two Cuvierian ducts, into the auricle. The upper part of this remains to constitute the upper part of the Inferior Cava (Figs. 181, 182, *j*), the lower portion of which arises between the Wolffian bodies, and originally enters the omphalo-mesenteric vein above the liver. The Inferior Cava, which receives the hepatic vein, is gradually enlarged by the reception of most of the veins from the inferior part of the trunk and the lower extremities, and the Vena Azygos is reduced in the same proportion; in some rare cases of abnormal formation, however, the vena cava fails to be developed, and then the blood from the lower parts of the body is conveyed to the superior cava through the system of the vena azygos.

775. The following is the course of the Circulation in the mature Fœtus.—The fluid brought from the Placenta by the umbilical vein, is partly conveyed at once to the ascending Cava by means of the ductus venosus, but chiefly flows through the vena portæ into the Liver, whence it reaches the ascending Cava by the hepatic vein. Having thus been transmitted through the great depurating organ, the Placenta, and the great assimilating organ, the Liver,‡ it is in the condition of arterial blood; but, being mixed in the great vessels with that which has been returned from the trunk and lower extremities, it loses this character in some degree, by the time that it arrives

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* See Müller's "Vergleichende Anatomie der Myxinoiden," Berlin, 1840.

† See the elaborate Memoirs 'On the Development of the Great Anterior Veins Man and Mammalia' ("Phil. Trans.," 1850), by Mr. J. Marshall; who has further shown that some vestiges of the original arrangement may be traced even in the normal condition of the venous system in the adult.

‡ It does not seem probable that the depurating action of the Liver can be energetically performed during fœtal life; and its large dimensions and copious supply of blood appear rather to be referable to its function as a *blood-making* gland (§ 156).

at the Heart. In the right auricle, which it then enters, it would be also mixed with the venous blood brought thither by the descending Cava; were it not that a very curious provision exists to prevent (in great degree, if not entirely) any such further dilution. The Eustachian valve has been found, by the experiments of Dr. J. Reid,* to serve the purpose of directing the *arterial* blood, which flows upwards from the *ascending* Cava, through the foramen ovale, into the *left* auricle, whence it passes into the *left* ventricle; whilst it also directs the *venous* blood, that has been returned by the *descending* Cava, into the *right* ventricle. When the ventricles contract, the arterial blood which the left contains is propelled into the ascending Aorta, and supplies the branches that proceed to the head and upper extremities, before it undergoes any admixture; whilst of the venous blood contained in the right ventricle, part is transmitted by the Pulmonary artery to the lungs, but another (and probably by far the larger) part finds its way through the Ductus Arteriosus into the descending Aorta, mingling with the arterial current which that vessel previously conveyed, and passing thus to the trunk and lower extremities. Hence the head and superior extremities, whose development is required to be in advance of that of the lower, are supplied with blood nearly as pure as that which returns from the placenta; whilst the rest of the body receives a mixture of this with what has previously circulated through the

FIG. 184.

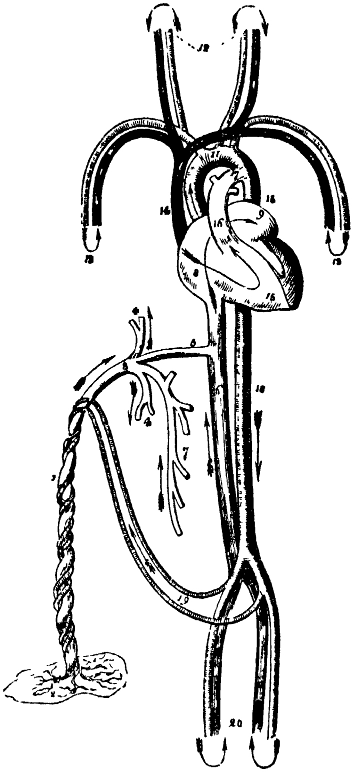

Diagram of the *Fœtal Circulation:*—1. The umbilical cord, consisting of the umbilical vein and two umbilical arteries, proceeding from the placenta (2). 3. The umbilical vein dividing into three branches; two (4, 4) to be distributed to the liver, and one (5), the ductus venosus, which enters the inferior vena cava (6). 7. The portal vein, returning the blood from the intestines, and uniting with the right hepatic branch. 8. The right auricle; the course of the blood is denoted by the arrow proceeding from 8, to 9, the left auricle. 10. The left ventricle; the blood following the arrow to the arch of the aorta (11), to be distributed through the branches given-off by the arch to the head and upper extremities. The arrows 12 and 13 represent the return of the blood from the head and upper extremities through the jugular and subclavian veins, to the superior vena cava (14), to the right auricle (8), and in the course of the arrow through the right ventricle (15), to the pulmonary artery (16). 17. The ductus arteriosus, which appears to be a proper continuation of the pulmonary artery; the offsets at each side are the right and left pulmonary arteries cut off. The ductus arteriosus joins the descending aorta (18, 18), which divides into the common iliacs, and these into the internal iliacs, which become the umbilical arteries (19), and return the blood along the umbilical cord to the placenta, and the external iliacs (20), which are continued into the lower extremities. The arrows at the termination of these vessels mark the return of the venous blood by the veins to the inferior cava.

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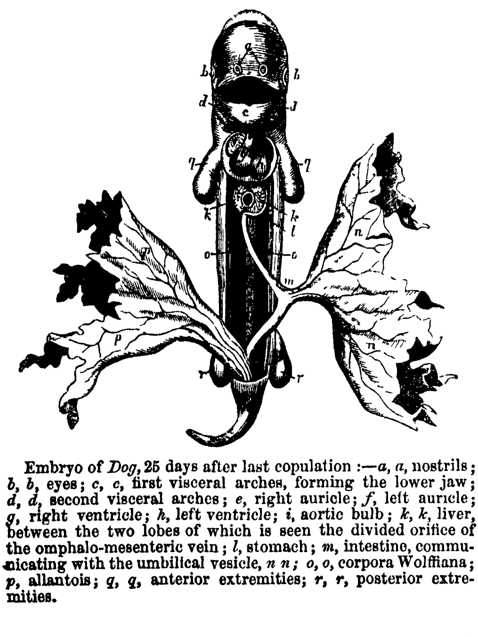
* "Edinb. Med. and Surg. Journal," vol. xliii.; and "Anat., Physiol., and Pathol. Researches," chap. ix.

system; and of this mixture a portion is transmitted to the placenta, to be renovated by coming into relation with the maternal fluid.—At birth, the course of the current is entirely changed by the cessation of the circulation through the Placenta, and by the enormous increase in the quantity transmitted to the Lungs, which takes-place immediately on the first inspiration: the Ductus Venosus and Ductus Arteriosus soon shrivel into ligaments; the Foramen Ovale becomes closed by its valve; and the circulation, which was before carried on upon the plan of that of the higher Reptiles, now becomes that of the complete Bird or Mammal.* It is by no means unfrequent, however, for some arrest of development to prevent the completion of these changes; and various malformations, involving an imperfect discharge of the function, may hence result. From the above description it is obvious that the chief propelling power in the circulation of the Fœtus is the right heart; the force of the left heart being chiefly spent in effecting a due supply of blood to the head and upper extremities: and a curious observation of Langer† is in accordance with this view, for he has shown that the walls of the right ventricle in the fœtus are as thick as those of the left, whilst those of the right auricle are even thicker and more muscular than those of the left auricle. This condition lasts for some days after birth, when the left heart gradually attains the superiority in thickness which is usual in adults.

FIG. 185.



Embryo of *Dog*, 25 days after last copulation :—*a, a*, nostrils; *b, b*, eyes; *c, c*, first visceral arches, forming the lower jaw; *d, d*, second visceral arches; *e*, right auricle; *f*, left auricle; *g*, right ventricle; *h*, left ventricle; *i*, aortic bulb; *k, k*, liver, between the two lobes of which is seen the divided orifice of the omphalo-mesenteric vein; *l*, stomach; *m*, intestine, communicating with the umbilical vesicle, *n n*; *o, o*, corpora Wolffiana; *p*, allantois; *q, q*, anterior extremities; *r, r*, posterior extremities.

776. The *Alimentary Canal* has been shown (§ 769) to have its origin in the blastodermic vesicle; being a portion

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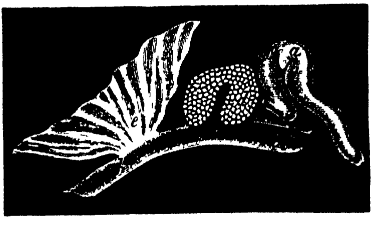
* It has been argued by Dr. Peaslee (of Dartmouth College, U.S.), that the above account is incorrect, since the diameter of the Ductus Arteriosus is so small in proportion to that of the Pulmonary arteries, that it can serve no other purpose than that of a 'waste-pipe' to carry-off the superfluous blood which they cannot receive. But he supposes the amount of blood transmitted through these vessels respectively, to be chiefly or entirely determined by their respective diameters; and takes no account of the numerous facts which *prove* that the quantity of blood transmitted to the lungs before birth, is *extremely small* in proportion to that which they receive so soon as the respiratory function is fully established. See his 'Monograph on the Fœtal Circulation,' in "American Medical Monthly," May, 1854.

† 'Zur Anatomie der Fötalen Kreislauforgane,' "Zeits. der Gesell. d. Wien," xiii. p. 328.

pinched-off (as it were) from that part of it which is just beneath the spinal column of the embryo, whilst the remainder, which is at that time the largest part of it, forms the vitelline or umbilical vesicle. In its earliest form it is merely a long narrow tube (Fig. 185, *m*), nearly straight, and communicating with the umbilical vesicle (*n*, *n*) at about the middle of its length; thus it may be regarded as composed of the union of two divisions, an upper and a lower. At first, neither mouth nor anus exists; but these are formed early in the second month, if not before. The tube gradually manifests a distinction into its special parts, œsophagus, stomach, small intestine, and large intestine; and the first change in its position occurs in the stomach, which, originally disposed in the line of the body, afterwards takes an oblique direction. The curves of the large and small intestine present themselves at a later period. It is at the lower part of the small intestine, near its termination in the large, that the entrance of the vitelline duct persists; and a remnant of this canal is not unfrequently preserved throughout life, in the form of a small pouch or diverticulum from that part of the intestine.

777. In immediate connection with the intestinal tube, we find the first rudiment of the *Liver*, which is formed in the third week by the thickening of the cells in the wall of the canal, at the spot at which the hepatic duct is subsequently to discharge itself. This thickening increases, so as to form a projection upon the exterior of the canal; and soon afterwards the lining membrane of the intestine dips-down into it, so that a kind of cæcum is formed, surrounded by a mass of cells, as shown in Fig. 186. The increase of the organ seems to take-place by a continual new budding-forth of cells from its peripheral portion; and a considerable mass is thus formed, before the cæcum in its interior undergoes any extension by ramifications into it. Gradually, however, the cells of the exterior become metamorphosed into fibrous tissue for the investment of the organ; those of the interior break-down into ducts, which are developed in continuity with the cæcum derived from the intestine, and which are lined by muscular and fibrous tissues developed from the primitive cellular blastema; whilst those which occupy the intervening space, and which form the bulk of the gland, give origin to the proper secreting cells, which are now to come into active operation. As this is going-on, the hepatic mass is gradually removed to a distance from the wall of the alimentary canal; and the cæcum is narrowed and lengthened, so as to become a mere connecting pedicle, forming, in fact, the main trunk of the hepatic duct.—In the Human embryo, the formation of the Liver begins at about the third week of intra-uterine existence; the organ is from the first of very large size, when compared with that of the body; and between the third and the fifth weeks, it is one-half the weight of the entire

FIG. 186.

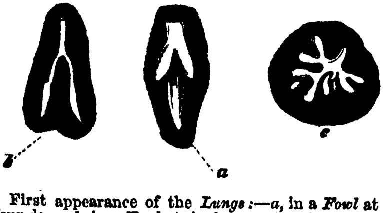


Origin of the *Liver* from the intestinal wall, in the embryo of the Fowl, on the fourth day of incubation:—*a*, heart; *b*, intestine; *c*, everted portion giving origin to liver; *d*, liver; *e*, portion of vitelline vesicle.

embryo. It is at that period divided into several lobes. By the third lunar month, the liver extends nearly to the pelvis, and almost fills the abdomen; the right side now begins to gain upon the left; the gall-bladder makes its first appearance at this time. The subsequent changes chiefly consist in the consolidation of the viscus, and the diminution of its proportional size. Up to the period of birth, however, the bulk of the liver, relatively to that of the entire body, is much greater than in the adult; the proportion being as 1 to 18 or 20 in the new-born child, whilst it is about 1 to 36 in the adult; and the difference between the right and left lobes is still inconsiderable. During the first year of extra-uterine life, however, a great change takes place; the right lobe increases a little or remains stationary, whilst the left lobe undergoes an absolute diminution, being reduced nearly one-half; and as, during the same period, the bulk of the rest of the body has been rapidly increasing, the proportion is much more reduced during that period, than in any subsequent one of the same length. According to Meckel, the liver of the newly-born infant weighs one-fourth heavier than that of a child eight or ten months old; and as the weight of the whole body is more than doubled during the same time, it is obvious that the change in the proportion of the two must be principally effected at this epoch. The liver seems to be engaged, during fœtal life, in the depuration of the blood (as appears from the accumulation of *meconium*, which is chiefly altered bile, in the intestinal canal at birth); but at the same time it is serving as a blood-making organ (§ 156), and this is probably its principal function before birth. The general history which has just been given of the development of the Liver, seems equally applicable to the other glands that are evolved from the parietes of the Alimentary canal, such as the *Salivary glands* and *Pancreas;* since they all seem to commence in little masses of cells, formed by an increased development, at certain spots, of the layer of blastema which originally constitutes its wall; and whilst some of these cells give origin to the proper vesicles of each gland, others form its ducts and tubuli by their deliquescence.—The development of the *Spleen* and of the *Supra-Renal*, *Thymus*, and *Thyroid* bodies, has been already described (§§ 131-136).

778. The *Lungs* are also developed in immediate relation with the upper part of the Alimentary canal, their first rudiments shooting-forth as a pair of bud-like processes (Fig. 187, *a*) from its œsophageal portion. These were originally described by Von Bär as hollow, and as being in reality *diverticula* from the tube itself. But most later observers agree in stating that the bud-like processes are not at first hollow, but are solid aggregations of cells, formed by a multiplication of the cells constituting the external wall of the alimentary tube, into which its internal tunic is not prolonged. These gradually increase in size, extending

FIG. 187.



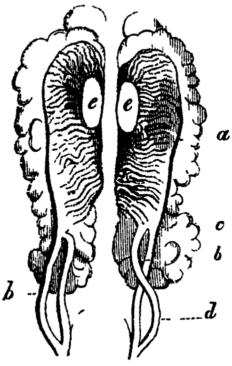
First appearance of the *Lungs*:—*a*, in a *Fowl* at four days; *b*, in a *Fowl* at six days; *c*, termination of bronchus in a very young *Pig*.

downwards by the multiplication of their component cells in that direction; and cavities are formed in them (probably, as in the preceding instances, by the deliquescence or fusion of some of the cells of their interior), which at first communicate with the pharynx by separate apertures; these, however, coalesce into one, as the channels are elongated into tubes, and the pulmonary organs are removed to a distance from their point of exit.—The first appearance of the Lungs, *in the Human embryo*, takes-place at about the 6th week, at which time they are simple elevations of the external layer of the œsophageal wall; from this, however, they are soon removed; each rudimentary lung having its own bronchial tube, connecting it with a trachea common to both (Fig. 187, *b*). Their surface becomes studded with numerous little wart-like projections, which are caused by the formation of corresponding enlargements of their cavity; these enlargements soon become prolonged, and develope corresponding bud-like enlargements from their sides; and in this manner the form of the organs is gradually changed, a progressive increase in their bulk taking-place from above downwards, in consequence of the extension of the bronchial ramifications of the single tube at the apex. At the same time, however, a corresponding increase in the amount of the parenchymatous tissue of the lung is taking-place; for this is deposited in all the interstices between the bronchial ramifications, and might be compared with the soil filling-up the spaces amongst the roots of a tree. It is in this parenchyma that the pulmonary vessels are distributed; and the portion of it which extends beyond the terminations of the bronchial tubes, seems to act as the nidus for their further extension. It can be easily shown that, up to a late period of the development of the lungs, the dilated terminations of the bronchi constitute the only air-cells (Fig. 187, *c*); but, as already mentioned, the parenchyma subsequently has additional cavities formed within it.—It is a fact of some interest, as an example of the tendency of certain diseased conditions to produce a return to forms which are natural to the fœtal organism, or which present themselves in other animals, that up to a late period in the development of the Human embryo, the lungs do not nearly fill the cavity of the chest, and the pleura of each side contains a good deal of serous fluid.

779. The embryological development of the *Urinary* organs in Vertebrated animals is a subject of peculiar interest; owing to the correspondence which may be traced between the transitory forms they present in the higher classes, and their permanent condition in the lower. In this respect, there is an evident analogy with the Respiratory system. The first appearance of anything resembling a Urinary apparatus in the Chick, is seen on the second-half of the third day. The form at that time presented by it, is that of a long canal, extending on each side of the spinal column, from the region of the heart, towards the allantois (Fig. 185, *o*, *o*, seen also in transverse section in Fig. 173, *ung*); on the sides of this are a series of elevations and depressions, indicative of the incipient development of cæca. On the 4th day, the *Corpora Wolffiana*, as they are then termed, are distinctly recognized as composed of a series of cæcal appendages, which are attached along the whole course of the first-mentioned canal, opening into its outer side (Fig. 188, *a*), and clearly developed from the middle lamina of the blastodermic vesicle (Figs. 173, 190). On the 5th

day these appendages are convoluted, and the body which they form acquires increased breadth and thickness; they evidently then possess a secreting function, and the fluid which they separate is poured by their long straight canals (*b*, *b*) into the cloaca; and between their component shut sacs, numbers of small points appear, which consist of little clusters of convoluted vessels, exactly analogous to the Corpora Malpighiana of the true kidney. These bodies remain as the permanent urinary organs of Fishes; but in the higher Vertebrata they give place to the true Kidneys, the development of which commences in the Chick about the 6th day. These when first seen, are lobulated greyish masses (*c*), which seem to sprout from the outer edges of the Wolffian bodies, but which are really independent formations, springing from a mass of blastema behind them; and as they gradually increase in size and advance in development, the Wolffian bodies retrograde; so that at the end of fœtal life, the only vestige of them is to be found as a shrunk rudiment, situated (in the male) near the testes, to which their excretory ducts serve as the outlets, becoming the 'vasa deferentia.'—The history of the development of the Urinary organs in the Human embryo, seems to correspond closely with the foregoing. The Wolffian bodies begin to appear towards the end of the first month; and it is in the course of the 7th week, that the true Kidneys first present themselves. When at their greatest development, the Corpora Wolffiana are the most vascular parts of the body next to the liver; four or five branches from the aorta are distributed to each, and two veins are returned from each to the vena cava. The upper arteries and their corresponding veins are afterwards converted into the Renal or emulgent vessels; and the lower into the Spermatic vessels. From the beginning of the 3rd month, a diminution takes-place in the size of the Wolffian bodies, *pari passu* with the increase of the Kidneys; and at the time of birth, scarcely any traces of the former can be found. At the end of the 3rd month, the Kidneys consist of seven or eight lobes, the future pyramids; their excretory ducts still terminate in the canal, the *sinus urogenitalis*, which receives those of the Wolffian bodies (subsequently to become the vasa deferentia), and of the Fallopian tubes;* and this opens, with the rectum, into a sort of *Cloaca*, analogous to that which is permanent in the oviparous Vertebrata. The Kidneys are at this time covered by the Supra-Renal capsules, which equal them in size; about the 6th month, however,

FIG. 188.



State of the *Urinary* and *Genital Apparatus* in the early embryo of the Bird.—*a*, corpora Wolffiana; *b*, *b*, their excretory ducts; *c*, kidneys; *d*, ureter; *e*, *e*, testes.

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* Although it has been usually considered that the Vasa Deferentia of the male and the Fallopian tubes of the female, are homologous organs, yet this does not seem really to be the case; for the former are derived from the excretory ducts of the Wolffian bodies, whilst the latter are independent formations, which are found to co-exist with seminal ducts at an early period of development, alike in male and in female embryoes. (See Kobelt, "Der Nebeneirstock des Weibes," Heidelberg, 1847.) The ducts of the Wolffian bodies, although subsequently disappearing in the females of most Mammals, remain permanent as 'Gaertner's canals' in the female Ruminants and Pig.

these have decreased, whilst the kidneys have increased, so that their proportional weight is as 1 to 2½. At birth, the weight of the Kidneys is about three times that of the Supra-Renal capsules, and they bear to the whole body the proportion of 1 to 80; in the adult, however, they are no more than 1 to 240. The lobulated appearance of the kidney gradually disappears; partly in consequence of the condensation of the areolar tissue which connects its different portions, and partly through the development of additional tubuli in the interstices.—The Urinary Bladder is formed quite independently of the secreting apparatus, being an enlargement of a portion of the *pars urinaria* of the 'uro-genital sinus' (§ 781).

780. The essential parts of the *Generative Apparatus*, namely the Testes in the male, and the Ovaria in the female, are first developed in such immediate proximity with the Corpora Wolffiana (Fig. 188, *e*, *e*), that they have been supposed to sprout-forth from them; this, however, is not really the case, as they have an independent origin in a mass of blastema peculiar to themselves. They make their first appearance in the Chick, as delicate striæ on the Wolffian bodies, about the fourth day; at which period no difference can be detected between the Testes and the Ovaria, which originate in precisely the same manner. In the Human embryo, the rudiments of the sexual organs,—whether testes or ovaria,—first present themselves soon after the kidneys make their appearance, that is, towards the end of the 7th week. They are originally much prolonged, and seem to consist of a kind of soft, homogeneous blastema, in which the structure characteristic of each organ subsequently developes itself. The *Testis* gradually assumes its permanent form; the epididymis appears in the tenth week; and the gubernaculum (a membranous process from the filamentous tissue of the scrotum, analogous to the round ligament arising from the labium and attached to the ovary of the female), which is originally attached to the vas deferens, gradually fixes itself to the lower end of the testis or epididymis. The Testes begin to descend at about the middle period of pregnancy; at the seventh month they reach the inner ring; in the eighth they enter the passage; and in the ninth they usually descend into the scrotum. The cause of this descent is not very clear: it can scarcely be due merely, as some have supposed, to the contraction of the gubernaculum; since that does not contain any fibrous structure until after the lowering of the testes has commenced. It is well known that the testes are not always found in the scrotum at the time of birth, even at the full period. Upon an examination of 97 new-born infants, Wrisberg found both testes in the scrotum in 67, one or both in the canal in 17, in 8 one testis in the abdomen, and in 3 both testes within the cavity. Sometimes one or both testes remain in the abdomen during the whole of life; but this circumstance does not seem to impair their function.* This condition is natural, indeed, in the Ram. —The *Ovary* undergoes much less alteration, either in its intimate structure, or in its position. Its efferent canal (which, as just stated, is *not* the representative of the vas deferens of the male) remains detached from it, having a free terminal aperture, and thus constituting the Fallopian tube. The *Uterus* (which was formerly supposed to be formed by

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* A case has lately occurred within the Author's knowledge, in which both testes remained in the abdomen until the tenth year, and then descended.

the coalescence of the Fallopian tubes), is now known to be derived, like the *Vagina*, from the genital portion of the 'uro-genital sinus' (§ 781), which is formed exactly on the same plan in both sexes alike, at an early period of fœtal development, and receives at its upper extremity the terminations of the Fallopian tubes. In the Female, this canal increases in size; and a marked separation is established between its lower or vaginal portion and its upper or uterine portion. The former opens into the undivided portion of the uro-genital sinus, which also receives the terminations of the urethra and of the Wolffian ducts, and which remains permanently unclosed. In the Male, on the other hand, the *sinus genitalis* makes no advance in development, and diminishes in relative size; so that at the period of fœtal maturity, it is only discoverable as the *vesicula prostatica*, which has been supposed until recently to be an appendage to the prostate gland. A transverse constriction in this canal marks-out its vaginal from its uterine portion; the former having exactly the same relation as in the female to the terminations of the urethra and of the Wolffian ducts (vasa deferentia) in the 'uro-genital sinus,' which is subsequently closed-in, however, so as apparently to form a continuation of the urethral canal; and the latter, in those Mammals whose females have a 'uterus bicornis,' exhibiting a like divarication into two lateral halves.*

781. The history of the development of the *external Organs of Generation* in the two sexes, presents matter of great interest, from the light which is thrown by a knowledge of it upon the malformations of these organs, which are among the most common of all departures from the normal type of Human organization.—Not only is the distinction of sexes altogether wanting at first; but the conformation of the external parts of the apparatus is originally the same in Man and the higher Mammalia as it permanently is in the Oviparous Vertebrata. For, about the 5th or 6th week of embryonic life, the opening of a *cloaca* may be seen externally, which receives the termination of the intestinal canal, the ureters, and the efferent ducts of the sexual organs; but at the 10th or 11th week, the anal aperture is separated from that of the genito-urinary canal or 'uro-genital sinus,' by the development of a transverse band; and the uro-genital sinus itself is gradually separated by a like process of division, into a 'pars urinaria' and a 'pars genitalis,' the former of which, extending towards the urachus, is converted into the urinary bladder. A partial representation of this phase of development is found in the permanent condition of the Struthious Birds and of the Implacental Mammalia. The external opening of this canal is soon observed to be bounded by two folds of skin, the rudiments of the labia majora in the female, and of the two halves of the scrotum in the male; whilst between and in front of these, there is formed an erectile body, surmounted by a gland, and cleft or furrowed along its under surface. This body in the female is retracted into the genito-urinary canal, and becomes the clitoris, whilst the margins of its furrow are converted into

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* See Prof. E. Weber's "Zusätze zur Lehre vom Baue und den Verrichtungen der Geschlechtsorgane," Leipzig, 1846; and Dr. Leuckart's Art. 'Vesicula Prostatica' in "Cyclop. of Anat. and Physiol.," vol. iv.—It was supposed by Prof. Weber, that the vesicula prostatica is the homologue of the uterus alone; but the Author considers it to have been satisfactorily established by the researches of Dr. Leuckart, that it answers to the uterus and vagina conjointly.

the nymphæ or labia minora; and these bound the 'atrium vaginæ' or 'vestibule,' which receives the orifices of the urethra, of the vagina, and of Gaertner's canals when they are present, and which exactly represents, therefore, the 'sinus genitalis' of the early embryo. In the male, on the other hand, this sinus is nearly closed-in at a very early period, by the adhesion of the two folds of integument which bound it, forming that portion of the genito-urinary canal (improperly termed the 'urethra,') which receives the orifices of the vesical or true urethra, of the genital sinus (vesicula prostatica), and of the vasa deferentia; the erectile body increases in prominence, and becomes the penis; whilst the margins of the furrow at its under surface unite (at about the 14th week), to form the anterior continuation of the now-contracted genito-urinary canal, which is commonly termed the spongy portion of the urethra.

782. Now in a large proportion of cases of so-called *Hermaphrodism*, there has been either a want of completeness in the development of the Male organs, so that they present a greater or less degree of resemblance to those of the female; or the developmental process has gone-on to an abnormal extent in the Female organs, so that they come to present a certain degree of resemblance to those of the male.—One of the most common malformations of the *male* organ is 'hypospadias,' or an abnormal opening of the urethra at the base of the penis, arising from incompleteness in the closure of the edges of its original furrow. But when the developmental process has been checked at an earlier period, the uro-genital sinus may retain more nearly its original character, and may have a wide external opening beneath the root of the penis, so as to resemble the female vagina, whilst the penis is itself destitute of any trace of the urethral canal; in some of these cases, again, the testes have not descended into the scrotum; whilst the absence of beard, the shrillness of the voice, and the fulness of the mammæ, have contributed to impart a feminine character to these individuals, their male attributes, however, being determined by the *seminiferous* character of the essential organs, the testes.*—In the *female* organs, on the other hand, a greater or less degree of resemblance to those of the male may be produced by the enlargement of the clitoris, by its furrowing or complete perforation by the urethra, by the closure of the entrance of the vagina and the cohesion of the labia, so as to present a likeness to the unfissured perineum and scrotum of the male, by the descent of the ovaries through the inguinal ring into the position of the male testes, and by the imperfect development of the uterus and mammæ; with these abnormalities are usually associated roughness of the voice and growth of hair on the chin, and a psychical character more or less virile. —*True* Hermaphrodism, in which there is an absolute combination of the essential male and female organs in the same individual, is comparatively rare. It may occur under the forms of *lateral* hermaphrodism, in which there is a genuine ovary on one side and a testis on the other, in which case the external organs are usually those of a hypospadic male; *transverse* hermaphrodism, in which the external and internal organs do not correspond, the former being male and the latter female, or *vice versâ*;—

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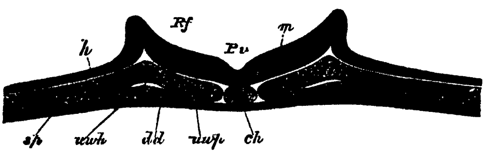
* The *vesicula prostatica* has presented an unusual development in some of these cases; see Prof. Weber (loc. cit.), and Prof. Theile's 'Account of a Case of Hypospadias,' in "Müller's Archiv," 1847.

and *double* or *vertical* hermaphrodism, in which the proper organs characteristic of one sex have existed, with the addition of some of those of the other; this is the rarest of all, and it is not certain that the coexistence of testes and ovaria on the same side has ever been observed in the Human species.*

783. We have now to follow the course of the development of the principal organs of *Animal* life; and shall first notice that of the *Skeleton.* The first differentiation of parts that occurs in the middle lamina of (§ 766) is the formation of a solid cartilaginous rod, termed the notochord or chorda dorsalis (*ch*, Fig. 189), which extends throughout the whole length of the future vertebral column, and along the base of the cranium as far as the space between the auditory capsules, or even to that point which subsequently becomes the pituitary fossa. The chorda dorsalis is originally composed of nucleated cells, that in the first instance lie in contact with one another, but are soon separated by the development of intercellular substance or matrix, the whole being enclosed by a delicate sheath. The chorda dorsalis, though permanent in the lowest fishes, is only a transitory structure in Man and all the higher Vertebrata. Soon after the laying down of this cartilaginous rod, the portion of the middle lamina which immediately surrounds it (*uwp*, Fig. 189, *uw*, Fig. 190) becomes detached; and in the portion so separated the first rudiments of the vertebræ appear in the form of rings surrounding the chorda dorsalis. More externally, the middle layer, passing outwards and downwards, and forming what is known as the Ventral Lamina, subdivides into two by a split or fissure (*sp*), which is the first indication of the pleuro-peritoneal cavity, the external or parietal layer (*hpl*) forming the walls of the abdomen with their contained structures, and ultimately meeting on the median line and enclosing the abdominal cavity in the same way that the dorsal laminæ enclose the spinal cord, whilst the inner or fibrous layer (*df*) develops the muscular and fibrous layers of the intestinal canal, the innermost layer (*dd*) producing the proper epithelium and the several glands connected with the intestine. At this period the primitive aortæ (*ao*) and the first urinary organs or Wolffian bodies (*awh*) begin to be formed. These are developed in the material situated externally to the chorda dorsalis, constituting a portion of the middle lamina of the blastodermic vesicle (*uw*, Fig. 190), which now becomes separate and distinct from the remainder of the middle lamina. Soon after this period the prevertebral

FIG. 189.



Transverse section through the *Embryo of the Chick* at the close of the first day of incubation, magnified about 100 diameters:—*ch*, chorda dorsalis; *h*, external serous or corneal layer; *m*, medullary portion of serous layer; *Pv*, primitive groove between the dorsal laminæ *Rf* and *m*; *dd*, intestinal epithelial or glandular layer (mucous layer); *uwp*, prevertebral mass, in which the primary or protovertebræ are formed, and which is continuous with the middle lamina, *sp*; *uwh*, fissure in the middle lamina, presenting the first indication of the pleuro-peritoneal cavity, and of the subsequent division of the middle lamina into two layers.

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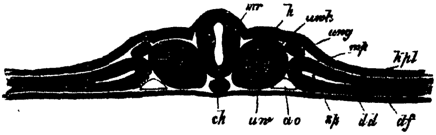
* On this subject, see Prof. Simpson's Article 'Hermaphrodism' in the "Cyclop. of Anat. and Phys.," vol. ii.

masses (*uw*) extend themselves so as to embrace the chorda dorsalis below and the spinal cord above; the part where the two sides unite above being called by Rathke the *membrana reuniens superior*, or membranous vertebral arch. A portion of the prevertebral mass also insinuates itself between the chorda dorsalis and the spinal cord, so that the former is entirely invested by it, and a complete vertebral column is formed, though still only *membranous*, presenting two tubes, the one posterior, formed by the arches, and inclosing the spinal cord, the other anterior, investing the chorda dorsalis. In the membranous arches an histological differentiation takes place, by which, on the one hand, the cartilaginous arches are developed, and on the other the anterior and posterior roots of the spinal nerves (*v*, *g*, Fig. 174).

Fig. 190.



Transverse section made through the *Embryo of a Fowl* at the thirty-sixth hour of incubation × 100:—*ch*, chorda dorsalis; *h*, external lamina; *mr*, medullary tube (spinal cord); *dd*, intestinal glandular layer; *aw*, prevertebral mass; *awh*, incipient cavity in the same; *sp*, split in the middle lamina, dividing it into an external or parietal lamina, *hpl*, and an internal or fibrous layer, *df*, which are connected by a median lamina, *mp*. The position of the Wolffian bodies is represented by *ung*, and of the primitive aorta by *ao*.

784. The formation of *cartilage* constitutes the second stage of the development of the vertebral column. It commences about the 6th or 7th week of fœtal life, and rapidly extends over the bodies of the future vertebræ, so that already, in the 8th week, a complete cartilaginous column with a membranous intervertebral ligament is formed; the chorda dorsalis now becomes attenuated and begins to disappear in the bodies of the vertebræ (Fig. 191), whereas it still remains distinct in the Ligamenta intervertebralia, and consequently presents a moniliform appearance. The formation of cartilage, which, according to Robin,* is everywhere developed before the substance of the brain and spinal cord, takes place much more slowly in the vertebral arches, not being more advanced at the 8th week than is shown in Fig. 192; so that at this period the medulla spinalis and its ganglia are only covered by the

Fig. 191.

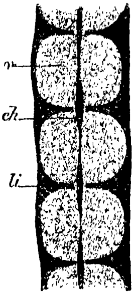


Fig. 192.

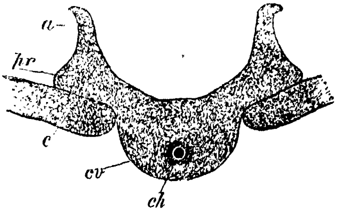


Fig. 191.—Diagram showing the attenuation of the *Chorda Dorsalis* in the middle of the bodies of the vertebræ whilst preserving its original diameter in the invertebral spaces:—*ch*, chorda dorsalis; *v*, body of vertebra; *li*, intervertebral substance.

Fig. 192.—Diagram showing the position of the chorda dorsalis in the body of the vertebra and the formation of the neural arches:—*ch*, chorda dorsalis; *cv*, body of the vertebra; *a*, neural arch or neur-apophysis; *c*, rib; *pr*, transverse process.

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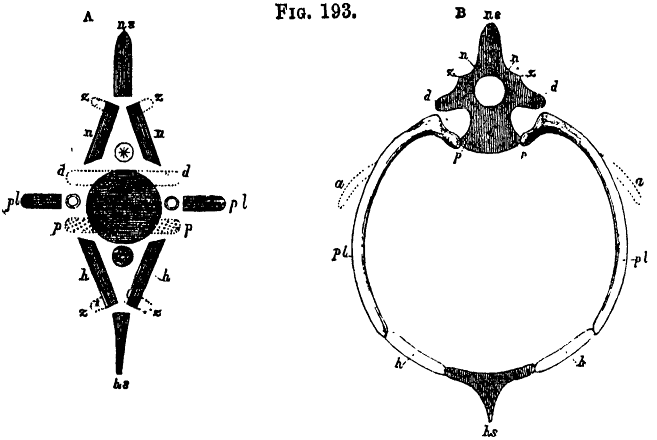
* Robin's "Journal de l'Anatomie," vol i., 1864, pp. 274–299.

membrana reuniens superior. The arches first meet and enclose the medulla in the dorsal region; in the 4th month this is completed throughout the column, and, except in the coccygeal region, where no arches are developed, the form of the future vertebræ, in which ossification has already commenced, is perfect. The development of the atlas is irregular, its body, which is originally traversed by the chorda dorsalis, as shown by Rathke and Robin, becoming connected, not with its proper arch, but with the body of the axis forming the odontoid process of this vertebra. The ossification of the vertebræ begins at the end of the 2nd or the beginning of the 3rd month, with three centres for each vertebra, one for the body and one for the arch on each side. These parts, however, do not unite till the second year after birth. Accessory centres of ossification are subsequently formed at the tips of the spinous and transverse processes, and in the form of thin leaves at the upper and lower surfaces of the bodies, which resemble the epiphyses of the long bones. The cartilages of the ribs do not develope at once in their whole length, but gradually from the spine towards the sternum. Their ossification proceeds contemporaneously with those of the vertebræ from one centre for each rib, the anterior extremities of the upper seven uniting together to form a broad cartilaginous band, which constitutes one lateral half of the *sternum*, the two halves subsequently uniting from above downwards. An arrest of this mode of development explains the monstrosity called 'Fissura Sterni,' a case of which, in the person of M. Groux, lately excited so much interest in this country.

FIG. 193.



Elements of a *Vertebra* according to Prof. Owen:—A, ideal typical vertebra:—B, actual thoracic vertebra of a Bird:—*c*, centrum, giving-off *d*, *d*, the diapophyses, and *p*, *p*, the parapophyses; the neural arch, enclosing the spinal cord,* is formed by *n*, *n*, the neurapophyses, and ***n s***, the neural spine; the hæmal arch, enclosing the great centres of the circulation, is formed by ***h***, ***h***, the hæmapophyses, and ***h s***, the hæmal spine. From both the neurapophyses and hæmapophyses may be given-off the zygapophyses, *z*, *z*. The lateral arches, which may enclose the vertebral arteries o o, are completed by the pleurapophyses, *pl*; these in B are bent downwards, so as to form part of the hæmal arch, and give-off the diverging appendages *a*, *a*.

785. In order to facilitate the comprehension of terms now very generally employed both in Human and Comparative Anatomy in regard to the parts of a vertebra, the following description is here appended. The complete *typical vertebra* (Fig. 193, A) essentially consists

according to Prof. Owen,* of the *centrum*, around which are arranged four arches enclosed by processes in connection with it: viz., superiorly, the *neural* arch, which encloses the neural axis, and is formed by a pair of 'neurapophyses' (*n*, *n*) and a 'neural spine' (*ns*); inferiorly the *hæmal* arch, which is in like special relation with the centres of the circulation, but may be expanded around the Visceral cavity generally, and which is formed of a pair of 'hæmapophyses' (*h*, *h*) and the 'hæmal spine' (*hs*); and two *lateral* arches, enclosing vascular canals, which are bounded by the 'diapophyses' (*d*, *d*) and the 'parapophyses' (*p*, *p*), and are completed by the 'pleurapophyses' (*pl*, *pl*). Of these elements, the centrum is the most constant; and next to these are the neural arches, which we find in every part of the vertebral column through which the neural axis passes, and which are enormously developed in the cranial segments, in accordance with the high development of their nervous mass. The hæmal arches are often almost entirely deficient, as in the cervical and lumbar vertebræ of Man and the Mammalia; but in the dorsal vertebræ they are very largely developed, and the elements of the lateral arches are brought into connection with them, so as to form the inclosure of the visceral cavity (Fig. 193, B). From the pleurapophyses are occasionally developed a pair of 'diverging appendages' (*a*, *a*), which are well seen in the ribs of Birds; and these are considered by Prof. Owen to be the fundamental elements of the bones of the 'extremities' or 'limbs,' those of the anterior extremity being on his view the diverging appendages of the occipital vertebra, and those of the posterior extremity standing in the same relation to one of the sacral vertebræ. The number of the segments analogous to Vertebræ entering into the skull has been a subject of much discussion among those who adopt the 'vertebral theory' of its composition: but Prof. Owen agrees with Goethe and Oken (the original propounders of that theory) in fixing the number at *four*, which corresponds with the points of ossification, succeeding each other in a linear series, that, though absent in the earlier, are apparent in the later stages of the development of the Encephalon, namely (proceeding from behind forwards), the Epencephalon, the Mesencephalon, the Prosencephalon, and the Rhinencephalon (Fig. 199); and also corresponding with the number of the nerves of special sense, the Auditory, Gustative, Optic, and Olfactory, which issue from this part of the neural axis with the same segmental regularity that the ordinary sensori-motor nerves do elsewhere.

786. In the development of the Skull, the same three stages may be traced as in that of the Vertebral column, namely, the membranous, the cartilaginous, and the osseous; the result of the first two forming what is now called the Primordial Cranium. In the first stage, the membrane of the cranium is formed from the anterior part of the prevertebral plates (*uwh*, Fig. 190), which shoot forwards in front of the pointed extremity of the Chorda dorsalis or Notochord, and throw out processes on either side, that, arching upwards, ultimately form a case for the brain. An essential difference from those which, as we have just now seen, enclose the Spinal Cord, is however already visible, in the perfect continuity and absence of any trace of segmentation in the basal mass. The form assumed by this deposit at a very early period is here diagrammatically shown (Fig. 194),

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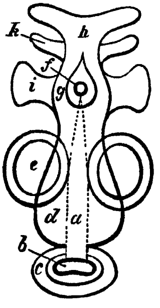
* See his "Archetype Skeleton," his "Lectures on Comparative Anatomy," vol. ii., and his "Discourse on the Nature of Limbs."

c representing the atlas, or last segment of the true vertebral column, formed round the notochord, *a*, which terminates at the point *g*, where the pituitary body subsequently appears. In front of the atlas, *c*, and also, like it, surrounding the notochord, a large quantity of blastema is laid down anteriorly, dividing into two arms, *g*, termed the trabeculæ cranii, that separate to enclose the pituitary fossa, and reunite in front of it to form a solid mass, the nasal frontal process. From the margins of this great basal mass of the primordial cranium, a membranous investment rises up to cover the intra-cranial nervous centres. This membranous cranium, which accurately invests the rudimentary brain, is not long persistent, but soon becomes partially converted into cartilage; the change commencing at the base in the Human fœtus at least as early as the second month, whilst the upper part retains its membranous condition to a much later period. The primordial cranial axis of Man, therefore, consists of three parts—1. A membranous roof; 2. Chiefly membranous lateral walls; and 3. A cartilaginous base. The third, or osseous stage of development, is attained by four different processes, namely—1. By direct ossification of a portion of the cartilage of the primordial cranium; 2. By part of the cartilage remaining unaltered; 3. By the disappearance of a small part of the primordial cartilage; and 4. By the deposition of new bone in the form of opercular, or splint bones, on the exterior of the primordial cranium.

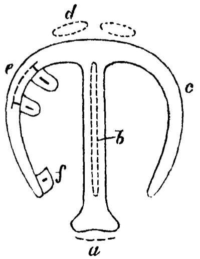
FIG. 194.



Cartilaginous basis Cranii:—*a*, chorda dorsalis; *b*, foramen magnum; *c*, atlas; *d*, lateral cartilaginous mass; *e*, auditory capsule; *f*, pituitary body; *g*, trabecula cranii; *h*, frontal nasal process; *i*, alæ majores; *k*, alæ minores of the sphenoid bone.

The first point of ossification appears immediately in front of the foramen magnum about the ninth week, and is the rudiment of the basilar portion of the occipital bone; a second (sometimes double) point forms in the third month at the fore part of the Sella turcica, and is the rudiment of the basisphenoid or posterior portion of the sphenoid bone. Still more anteriorly, but a little later in point of time, a third double centre of ossification may be seen, which is the commencement of the presphenoid, and in front of this again an ossification commences about the middle of fœtal life, which subsequently becoming greatly extended in a vertical direction, forms the perpendicular plate of the ethmoid. With each of these centres of ossification, situated along the floor or base of the skull, a superior arch is connected, composed of bones analogous to the laminæ and spines of the Vertebræ, and, like them, enclosing and protecting the nervous mass within. The formation of the superior arch in connection with the basioccipital centre commences at an early period, by the appearance of two additional ossifying points in the cartilage on either side of the foramen magnum, which develope into the condyloid and lateral portions of the occipital bone or exoccipitals; whilst the crown of the arch, or supra-occipital bone, represented in the adult by the broad expanded plate, is formed by two osseous points in cartilage, and one or two in the membrane immediately above the cartilage, that subsequently coalesce. The upper arch of the basisphenoid begins as a bony deposit in the cartilage representing the great wings of the sphenoid bone, or alisphenoids (*i*, Fig. 194); and the crown of this arch, formed by the parietals, is exclusively produced, not by intra-cartilaginous, but by intra-membranous ossification. A third upper arch is connected with the presphenoid by the ossification of the projections of the presphenoid (*k*), representing the alæ minores of the sphenoid or orbito-sphenoids; the crown of this arch also, the frontal bone, developing by intra-membranous ossification, like the parietal and supra-occipital bones. The most anterior of the centres of ossification that appears in the basal cartilage of the skull, forms the lamina perpendicularis of the ethmoid (*b*), and is seen in vertical section in Fig. 195. At an early period the cartilage sends out two processes, *c*, *e*, which enclose the nasal fossæ. The superior and middle turbinals (opposite *e*) are developed as outgrowths from this cartilage. The inferior turbinal (*f*) is of later date. The nasal bones, *d*, *d*, are developed as opercular bones in the membrane covering the primitive cartilage, and overlie the nasal cartilage; whilst at the base of the cartilage, but developed from membrane, is the vomer (*a*). The remaining bone which enters into the formation of the skull is the Temporal, the development of which, formerly much misunderstood, has been very carefully investigated by Prof. Huxley, Mr. Parker, and others; from whose inquiries it appears that the squamosal portion, like the parietal and frontal bones, is developed from membrane. Below this, and developed from fibro-cartilage, a ring of bone appears, incomplete above, forming the auditory meatus, and termed the tympanic bone. Finally, there are three centres of ossification, for which Mr. Huxley proposes the terms *prootic*, *epiotic* and *opisthotic*. The prootic lies behind the foramen ovale, and forms the petrosal bone, or petrous portion of the temporal. The epiotic surmounts the posterior vertical semicircular canals, and forms the mastoid portion of the temporal; whilst the opisthotic is continuous with the ossification which primitively surrounds the fenestra rotunda, and forms the floor of the Tympanum, lying in front of the point of exit of the 8th pair of nerves.

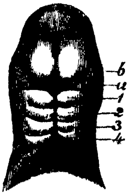
FIG. 195.



Vertical transverse section of anterior portion of *Primordial basis Cranii*:—*a*, position of vomer; *b*, perpendicular lamina of ethmoid; *c*, right ala of the cartilage, from which the turbinal bones, *e* and *f*, are seen projecting on the opposite side; *d*, nasal bones.

787. The development of the Face next claims our attention. It proceeds from three parts, two of which are symmetrical and the third single. The first two are the first pair of visceral arches, with their superior (*a*, Fig. 196) and inferior (1) maxillary processes, and the external nasal process: the asymmetrical part is the frontal process, with its alæ or internal nasal processes (seen on each side of *nf*, Fig. 197), the development of which into the turbinals, covered by the nasals, has been already alluded-to. The two lateral halves of the first visceral arch (1, Fig. 196) uniting in the middle line, form the rudiment of the lower jaw, and originally consist of two parts on each side, one of which, the inferior maxillary process, is cartilaginous, becoming converted at its base into

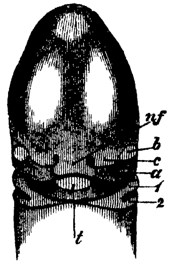
FIG. 196.



Human Embryo at the end of the third week:—1, 2, 3, 4, the visceral arches; *a*, the maxillary process; *b*, the eye.

the incus (*a*, Fig. 198) and the malleus (*b*); whilst its apex is prolonged downwards and forwards in the form of a slender rod, known under the name of Meckel's Cartilage, on the outer side of which the lower jaw (*d*) is developed as a splint-bone. The lower jaw thus stands in the same relation to Meckel's Cartilage that the opercular bones do to the primitive cranial bones; and it originally consists of two halves, united by a kind of synchondrosis, which does not ossify till after birth. The malleus and incus ossify in the fourth month from the surface inwards, whilst Meckel's cartilage dies away, except near its root, which ossifies into the processus gracilis, or long process of the malleus. The superior maxillary process (*a*, Fig. 197) of the first visceral arch furnishes the Pterygoid (*k*, Fig. 198) and Palatine (*i*) bones, which begin to ossify in nascent or simple cartilage at about the close of the second month. The superior maxillary and zygomatic bones each ossify from one centre, at the end of the second month; and these, together with the lachrymal bones, are to be regarded as opercular bones. With regard to the intermaxillary bone, it is probable that this is developed from an ossific centre in the membrane, independently of the superior maxilla, though it joins with it about the middle of the third month. The Vomer bears the same relation to the base of the septum nasale; it appears in the third month, and has then the form of a semi-canal. At first, the mouth is a wide cavity, which is subsequently divided into a respiratory and digestive cavity by the lateral growth of the superior maxillary processes of the first visceral arch; thus constituting partitions on either side, called Palate-plates, which after the eighth week begin to coalesce from before backward. An arrest of development at this period produces the deformity termed Cleft-palate. The second visceral arch is originally in connection with the base of the skull, near the posterior sphenoid bone, from which it becomes subsequently separated by absorption of its "proximal piece." This basal piece becomes the stapes (*e*, Fig. 198), and comes into relation with the labyrinth; it is at first imperforate, and ossifies from three centres later than the other bones. The second portion of the branchial arch, which does not become cartilage, furnishes the musculus stapedius; then follows a long piece of cartilage, which unites with the mastoid process of the primordial cranium, and

FIG. 197.



Human Embryo at the close of the fifth week:—1 and 2, the first two visceral arches; *a*, the superior maxillary process; *b*, the eye; *c*, the lateral naso-frontal process; *nf*, the nasal-frontal process; *t*, the tongue.

FIG. 198.

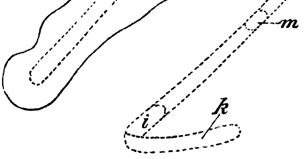


Diagram of the first and second poststomal (visceral) arches of *Human Embryo*:—*a*, incus; *b*, malleus; *c*, Meckel's cartilage; *d*, dentary; *e*, stapes; *f*, os orbiculare; *g*, upper hyoid cartilage; between *g* and *e* is the rudiment of the stapedius muscle; *m*, middle hyoid cartilage; *i*, rudiment of the cornu minor of os hyoides; *k*, basihyal; *l*, tympanic annulus.

furnishes the eminentia papillaris and the styloid process. The most anterior portion, which never unites with the corresponding portion of the other side, becomes partly cartilaginous, and furnishes the cornu minus (*i*) of the hyoid bone, and stylohyoid ligament. The third arch furnishes the body of the hyoid bone and great cornua, which ossify in the eighth month.

788. From the foregoing brief outline of the development of the skull, it will be seen that no segmentation of the *cartilaginous* basis takes-place at all analogous to that which occurs in the vertebral column at the same period of its development; and therefore, as Mr. Huxley observes, that it is impossible to admit the existence of a series of cranial vertebræ, still less to define their several parts by means of terms especially adapted to the description of those bones which constitute the spinal column. At the same time, a very superficial investigation of the process of ossification leads to the conclusion that this takes-place in such a manner as to produce a series of segments which are the more closely analogous to those of the vertebral column the more posteriorly they are situated, as we see in the occipital and sphenoid segments; whilst in those that are more anterior the modification of structure is so great, that scarcely any trace of the form of a vertebra remains, as appears in the case of the presphenoid and ethmoidal segments.

789. Within the Cranio-spinal canal thus formed, the rudiment of the Cerebro-spinal axis is found, at first under a very different aspect from that which it subsequently presents, especially as regards the relative proportion of its different segments. According to the investigations of Bidder, Kupffer, and Kolliker, in Man and Birds, the spinal cord consists, after the closure of the laminæ dorsales, of a canal surrounded by cells arranged in a radiating manner. These separate into an external layer composed of grey matter, and into an inner layer constituting the epithelium of the canal. The white substance appears later than the grey, and is unquestionably developed from it. In the first instance it consists of four cords or strands arranged in pairs, which subsequently become connected in front by a white commissure.* According to the researches of Lockhart Clarke, in Man, Mammalia, and Birds,† the spinal cord, in its earlier stages of development, consists of a canal surrounded by a homogeneous layer of small cells or nuclei, which are not distinguishable from each other in appearance, and are so closely aggregated as to seem in actual contact. This layer continues to increase in depth, and undergoes a differentiation into two—an inner or epithelial, and an outer or grey, layer; while at the same time the small cells of both layers are uninterrupted, connected by a continuous network of fibres which forms between them. As development progresses, a diversity of structure ensues in the grey substance; the cells or nuclei of the anterior grey substance becoming much larger than those of the posterior, and being connected by a coarser and more granular network. From these nuclei are developed a number of large roundish or irregular but adjacent cells, with thick nucleated walls which are connected with the surrounding network, and have precisely the same appearance as the connective tissue of parts external to the cord. It appears then, that in these early stages of development, there are at least two kinds of free nuclei in the grey substance of the cord. The one kind appear to develope the general

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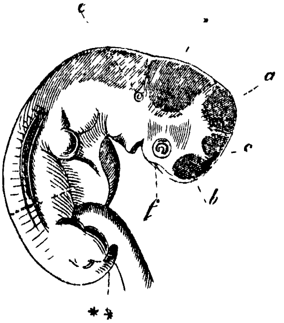
* Kölliker, "Entwick.," pp. 259, 260.

† "Phil. Trans.," 1862, p. 911 *et seq.*

network of tissue which pervades the entire structure, but proceed no further; whereas each of the other kind, while connected with this network as well as with nerve-fibres, develops a nucleated cell, with a nucleated wall which is still connected, and ultimately blended, with the surrounding reticular structure. Through the medium of this intervening reticular structure, the walls of the nerve-cells, the walls of the blood-vessels, the processes of the epithelium, and the pia mater on the surface of the cord, are all uninterruptedly continuous with each other; and since the processes of nerve-cells constitute the axis-cylinders of the vaso-motor nerves distributed to parts external to the cord, Mr. Clarke thinks it probable that some of those processes which are lost by subdivision in the intervening nucleated and reticular tissue *within* the cord, are the means of transmitting nerve-power to that tissue, and through that, to the coats of its blood-vessels, from which, by their uninterrupted connection with them, the nerve-cells, in return, receive their supply of nutriment.

790. The Encephalon, at about the 6th week, is seen as a series of vesicles arranged in a line with each other (Fig. 199); of which those that represent the Cerebrum (*b*) are the smallest, whilst that which represents the Cerebellum (*d*) is the largest. The latter (or *Epencephalon*), as in Fishes, is single, covering the fourth ventricle on the dorsal surface of the Medulla Oblongata. Anterior to this is the single vesicle (*a*) of the Corpora Quadrigemina (or *Mesencephalon*), from which the optic nerves partly arise; this has in its interior a cavity, the ventricle of Sylvius, which is persistent in the adult Bird, though obliterated in the adult Mammal. In front of this is the vesicle (*c*) of the Third Ventricle (or *Deutencephalon*), which also contains the Thalami Optici; as development proceeds, this, like the preceding, is covered by the enlarged Hemispheres; whilst its roof becomes cleft anteriorly on the median line, so as to communicate with the cavities which they include. Still more anteriorly (*b*) is the double vesicle (or *Prosencephalon*) which represents the hemispheres of the Cerebrum; this has a cavity on either side, the floor of which is formed by the Corpora Striata, and which has at first no opening except into the third ventricle; the 'fissure of Sylvius' (which enables the membranes of the brain to be reflected into the lateral ventricles) being formed at a later period. The *Rhinencephalon* (consisting of the Olfactive ganglia) is seldom distinctly marked-out in the early stage of development of the higher Vertebrata, though very obvious in that of Fishes.—Thus in the small proportion which the Cerebral Hemispheres bear to the other parts, in the absence of convolutions, in the deficiency of commissures, and in the general simplicity of structure of the whole, there is a certain correspondence between the

FIG. 199.

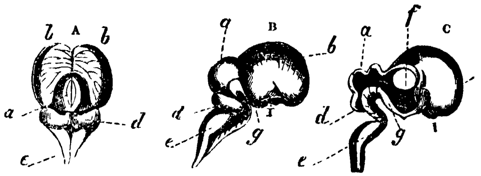


Human Embryo of sixth week, enlarged about three times:—*a*, vesicle of Corpora Quadrigemina; *b*, vesicle of Cerebral Hemispheres; *c*, vesicle of Third Ventrical; *d*, vesicle for Cerebellum and Medulla Oblongata; *e*, auditory vesicle; *f*, olfactory fossa; *h*, liver; * *, caudal extremity.

brain of the Human embryo at this period, and that of a Fish; but the resemblance is much stronger between the *fœtal* brain of the Fish and that of the Mammal; indeed at this early period of their formation, the two could scarcely be distinguished; and it is the large amount of change which the latter undergoes, as compared with the former, that causes the wide dissimilarity of their adult forms.

791. At about the 12th week, we find the Cerebral Hemispheres much increased in size, and arching-back over the Thalami and Corpora Quadrigemina (Fig. 200); still, however, they are destitute of convolutions, and are imperfectly connected by commissures; and there is a large cavity yet existing in the Corpora Quadrigemina, which freely communicates with the Third Ventricle. In all these particulars, there is a strong analogy between the condition of the brain of the Human embryo at this period, and that of the Bird.—Up to the end of the 3rd month, the Cerebral Hemispheres present only the rudiments of *anterior* lobes, and do not pass beyond that grade of development which is permanently characteristic of the Marsupial Mammalia, the Thalami being still but incompletely covered-in by them. During the 4th and part of the 5th months, however, the middle lobes are developed from their posterior aspect, and cover the Corpora Quadrigemina; and the posterior lobes, of which there was no previous rudiment, subsequently begin to sprout from the back of the middle lobes, remaining separated from them, however, by a distinct furrow, even in the brain of the mature fœtus, and sometimes in that of older persons. In these and other particulars, there is a very close correspondence between the progressive stages of development of the Human Cerebrum, and those which we encounter in the ascending series of Mammalia.[*]

FIG. 200.



Brain of *Human Embryo* at twelfth week:—A, seen from behind; B, side view; C, sectional view; *a*, corpora quadrigemina; *b*, *b*, hemispheres; *d*, cerebellum; *e*, medulla oblongata; *f*, optic thalamus; *g*, floor of third ventricle; I, olfactory nerve.

792. The development of the *Eye*[†] commences by a protrusion from the posterior part of the anterior cerebral vesicle, representing the 'vesicle of the thalami optici,' which is at that time hollow; and the cavity of the protrusion is continuous with that of the vesicle itself, which remains as the 'third ventricle.' At this period, according to Kölliker,

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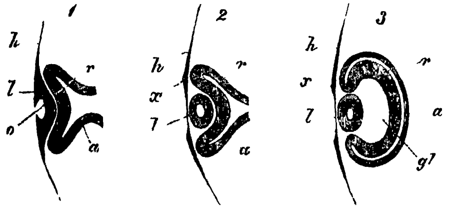
[*] See an account of the observations of Prof. Retzius on the Development of the Cerebrum, in the "Archives d'Anatomie Générale et de Physiologie," 1846.

[†] See the excellent Memoir of the late Mr. H. Gray in the "Philosophical Transactions," 1850; Kölliker, "Entwickel. des Menschen," 1861, p. 273; Peter Young, 'On the Development of the Eye in the Chick,' "Med.-Chir. Rev.," 1858, vol. xxii. p. 187; and Klebs in "Virchow's Archiv," band xxviii.

they are covered by the embryonic layers, which subsequently form the cutis and epidermis, and these enter to an important extent into the formation of the eyeball. The primitive eye-vesicle does not alone produce the Bulbus Oculi, for this is formed—1. From the primary vesicle; 2. From an involution of the skin, which forms the Lens and Vitreous body; 3. From an external layer derived from the middle layer of the blastodermic vesicle, which forms the Sclerotic cornea, and perhaps also part of the vitreous body. As soon as the primitive eye-vesicle has assumed its permanent position at the base of the second division of the brain, the corneal layer indents or sinks into its anterior surface, becoming itself so constricted as to form a sac, from the cells lining which the Lens is subsequently developed; whilst the vesicle in like manner forms a shallow depression with two layers, the edges of which surround the Lens. At the same time the cutis of the inferior surface of the Head extends itself from the Lens towards the primitive vesicle and its peduncle (which becomes at a later period the Optic Nerve). A new space is thus formed behind the Lens, which contains the first trace of the vitreous body. Coincidently with the growth of this, the optic nerve, which was at first hollow, becomes tapelike and solid, and afterwards converted into a semi-canal, open below. The vesicle itself now looks like a double flat cup, on one side of which there is a broad split, which, however, does not conduct into the interior of the vesicle, but forms a new cavity, the "secondary Eye-vesicle." With the progress of development, the slit of the secondary vesicle, and the furrow of the optic nerve, in which the Arteria centralis runs, close. In addition to this, the anterior opening of the secondary vesicle, in which the Lens was situated, and which was always covered by the epidermal layer, becomes invested with the Sclerotic and Cornea. The body of the Lens is formed by the columnar and radially-disposed epithelial cells lining the saccular involution of the cutis; these soon become changed into fibres, and the cavity is obliterated. As to the formation of the structureless capsule, and the vascular capsule of the embryonic lens, Kölliker considers the first to be an exudation of the peripheral cells of the lens, whilst the second is a portion of the cutis, which becomes detached at its first involution. The pigmentary layer of the Choroid is derived from the outer lamina of the secondary vesicle. The vascular layer is deposited externally. The Choroid only reaches as far as the edges of the lens at first, and no trace of Iris can at that time

Fig. 201.



Longitudinal section of the *Eye of Embryo Fowl*:—1, from an embryo at about the 65th hour of incubation; 2, from an embryo a few hours older; 3, from an embryo at the 4th day of incubation:—*h*, corneal lamina; *l*, lens in Fig. 1, still connected with the corneal lamina, and possessing a small cavity (*o*) in its interior,—in Figs. 2 and 3 it is seen detached but still hollow; *r*, introverted portion of the primitive optic vesicle, subsequently becoming the retina; *a*, posterior part of the optic vesicle, which, according to Remak, probably becomes the choroid coat, ciliary processes, and iris, and in Figs. 1 and 2 is still connected with the brain by the hollow optic nerve; *x*, thickening of the corneal lamina around the spot from which the lens has detached itself; *gl*, vitreous body.

be discovered. At the end of the second month the iris, at first represented by a colourless lamina in which pigment is afterwards deposited, grows out from the edge of the choroid, and insinuates itself between the lens and cornea. The Retina is, at first, part of the primitive, and at a later period, part of the secondary vesicle. It is derived exclusively from the internal lamina of the latter; it is therefore a true saccular involution of the brain, and the first-formed coat of the eye; it reaches the edge of the lens, and ends there abruptly with a thick edge. The development of its anterior half ceases during the latter part of fœtal life, and this part is gradually transformed into the Pars ciliaris, which in the adult does not contain any nervous element. The Macula lutea is not present in the embryo, nor in the new-born infant. Lastly, the Sclerotic and Cornea are not originally formed with the primary vesicle, but detach themselves secondarily from the adjacent parts of the Head-plates, like the dura mater and pia mater from the prevertebræ.

793. *Development of the Ear.*—The Ear is made up of parts which have the same threefold origin as the eye, one portion being derived from the skin, another from the medullary tube, and a third from the middle blastodermic layer; but it differs from the eye in the circumstance that it is never a sac communicating with the vesicles of the brain. The acoustic nerve is formed in the prevertebral plates of the head, and is subsequently connected on the one hand with the 3rd brain-vesicle, and on the other with the Labyrinth. The latter, including the membranous sacs, semicircular canals, and cochlea, are derived from the outer skin, and are represented at first by a vesicle with an opening looking outwards. To these two most essential parts of the Ear there are added parts derived from the middle vitelline membrane, viz., the cartilaginous and some of the membranous investments of the Labyrinth; and, lastly, certain parts from the branchial arches and the first branchial fissure, from which the middle and external ear are developed, as well as the ossicles and the tympanum. In Man the vesicles are first found about the 4th week, possessing an epithelial investment derived from the corneal layer: these are the Vestibula. The vesicles or vestibules then close and become pyriform; and the small end pushes out a hollow, club-shaped process, 'processus vestibuli,' which is connected with the dura mater, its peduncle passing through the Aquæductus vestibuli to the Atrium. Soon afterwards the Cochlea makes its appearance as a process from the vestibule, shooting in an antero-inferior direction. The Semicircular Canals are at first straight tubes, receiving their characteristic curvature and ampullæ at a later period. The remaining portion of the vestibule forms the Fovea hemispherica and the Fovea hemi-elliptica. The petrous portion of the temporal bone is developed from a thin layer of connective tissue surrounding the labyrinth, which subsequently becomes cartilaginous (8th week). In Man the cochlea makes one entire turn in the 8th week; at the end of the 3rd month the canal is complete. The Spiral Lamina is not completed till after the 6th month. —The modiola and the spiral lamina only ossify in the last months. The Middle Ear (including the external meatus, tympanum, and Eustachian tube) is formed by the partial closure of the first branchial cleft at the 4th week. At the 3rd month the ossicula are formed, and are then seen

lying *over*, not in, the tympanic cavity, imbedded in gelatinous tissue. The Eustachian tube remains closed during the whole of fœtal life by gelatinous tissue, the cartilaginous portion being formed at the 4th month. The mastoid cells only appear at puberty. The membrana tympani is at first very thick, and horizontal in position.—The *External Ear* is developed from the Annulus tympanicus, a small bone which can be separated at birth, and gradually elongates. The cartilage and auricle are formed from the skin that surrounds the outer opening of the first branchial cleft. The auditory capsule is developed, according to Huxley, from three separate ossifications arising in the periotic cartilaginous mass;—an anterior ossification, the prootic, a superior and posterior one, the epiotic, and an inferior and posterior one, the opisthotic. Of the three ossicula auditûs, the stapes is the proximal portion of the second visceral arch. It is the equivalent of the columella of air-breathing ovipara, and probably of the symplectic bone in fishes. The incus, with the os orbiculare, is the proximal portion of the first visceral arch. In the lower Vertebrata, it is represented by the os quadratum. The malleus is the distal portion of the first visceral arch, and is the modified os articulare of fish, reptiles, &c. The processus gracilis, at an early period of fœtal life, is the cartilage of Meckel, and meets its fellow in the middle line below the mouth, forming a perfect primordial lower jaw.

794. *Organ of Smell.*—According to Baer, the nasal fossæ are at first distinct from the oral cavity, subsequently communicate with it, and are finally divided into two portions, of which one becomes the respiratory portion of the nasal cavity, whilst the other forms the true olfactory portion and labyrinth of the Nose. In the Human subject two depressions, the nasal fossæ, are well marked at the end of the 4th week. In the 6th week these fossæ communicate below with the oral cavity by a groove. At the end of the 2nd month the groove closes, and the labyrinth communicates with the most anterior part of the oral cavity by means of two narrow orifices, which are themselves rapidly closed by the formation of the palate dividing the nose from the mouth, slight traces of them remaining in adult life in the Naso-palatine foramen. At the 10th week the posterior nasal orifices are formed on either side of the Septum. The Labyrinth is wholly developed from the corneal layer investing the nasal fossæ. It is fully formed at the close of the 3rd month, though the accessory cavities of the frontal, sphenoidal, and ethmoidal sinuses, with the antrum of Highmore, are yet absent, and are not completed till after the 6th month. The outer nose begins to grow out from the nasal part of the primordial cranium about the end of the 2nd month. In the 3rd month the nasal orifices are closed by a gelatinous plug, which disappears after the 5th month, and seems to consist of mucus and epithelial plates. As to the share of the nervous system, we have already seen that the olfactory tract and bulb are evolutions of the 1st brain-vesicle, and nothing is known in respect to the development of the nerves from the bulb. Here also, therefore, the corneal layer plays an important part. It is, however, never shut off as a closed vesicle. The several steps of the development of this organ are met with in the various classes of animals:

the small closed fossæ remind us of Fishes; the short nasal ducts opening into the anterior part of the mouth, of Batrachians, &c.

795. The extremities (Fig. 185, *q q*, *r r*) appear in Man about the fourth week, as small and undivided stumps from the lateral plate; those of the upper extremity appearing first: a division into two principal parts takes-place in the fifth week; one of which is broad, and shows about the fifth week four indentations; the other is more cylindrical, and subdivides into a fore and upper arm about the eighth week. The two extremities are very similar in form up to this period, their distinctive characters only appearing well marked at the third month. All the bones which enter into their composition pass through stages of development similar to those that have been already described as occurring in the bones of the vertebral column and skull. In the first instance only a soft blastema or indifferent tissue appears in the place of the future bone: but this gradually developes into cartilage, the conversion being complete about the end of the second or the commencement of the third month, and in the cartilage again points of ossification make their appearance, with great though not absolute precision, for each bone, not only as regards number, but also as to time and position.*

796. *Of Sex.*—The conditions on which the differentiation of sex immediately depend are as yet extremely obscure. M. Marc Thury,† who has paid great attention to this subject in cattle, has arrived at the conclusion (which however demands much confirmatory evidence for its establishment) that the sex of the progeny of a particular act of sexual intercourse is dependent upon the period of menstruation (in women), or of rut (in animals), at which the impregnation of the ovum takes-place. If this occur at the commencement of the period, the offspring will invariably be female; if towards the close, male: the cause of the difference being the more advanced stage of maturation of the ovum in the latter case, owing to its having been for a longer period exposed to the warmth of the body of the mother. Ploss‡ attributes the sex of the child to the quantity and quality of the nutriment received by the mother during pregnancy, since from a review of various countries, and a comparison of the relative numbers of males and females born, he finds that, when the food is abundant and plentiful, the proportion of females rises; whilst, under opposite conditions, males are most frequent. In mountainous countries the number of males also increases relatively. Preussen (loc. cit.), however, on the other hand, considers that better and more abundant food is required by the mother for the production of males. —There is strong statistical evidence that the relative numbers of Males and Females are in some way influenced by the relative *ages* of the parents. The following table expresses the average results collected by M. Hofacker§ in Germany, and by Mr. Sadler‖ in Britain; between which it will be seen that there is a very striking general correspondence, although both were drawn from a too-limited series of observations. The

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* See Kölliker, loc. cit., p. 222.

† "Notice on the Law of Production of Sexes, &c.," Pamphlet, 1863.

‡ Henle and Meissner, 1860, p. 210.

§ "Annales d'Hygiène," Oct. 1829.

‖ "Law of Population," vol. ii. p. 343.

numbers indicate the proportion of Male births to 100 Females, under the several conditions mentioned in the first column:—

	Hofacker.		Sadler.
Father younger than Mother .	90·6	Father younger than Mother .	86·5
Father and Mother of equal age	90·0	Father and Mother of equal age	94·8
Father older by 1 to 6 years .	103·4	Father older by 1 to 6 years .	103·7
,, ,, 6 to 9. . .	124·7	,, ,, 6 to 11 . .	126·7
,, ,, 9 to 18 . .	143·7	,, ,, 11 to 16 . .	147·7
,, ,, 18 and more.	200·0	,, ,, 16 and more .	163·2

From this it appears, that the more advanced age of the Male parent has a very decided influence in occasioning a preponderance in the number of Male infants; and this tallies with the fact, that taking the average of the whole of Europe, over which (as a general rule) the state and customs of society bring-about a decided preponderance of age, among married couples, on the side of the husband, the proportion is about 106 males to 100 females. This does not hold good, however, in regard to *illegitimate* offspring, the parents of which may generally be presumed to be more nearly on an equality in this respect; and it is curious that the proportion of these has averaged 102·5 males to 100 females, in places where the proportion of *legitimate* births was $105\frac{3}{4}$ males to 100 females. —We are not likely to obtain data equally satisfactory in regard to the influence of more advanced age on the part of the Female parent; as a difference of 10 or 15 years on that side is not so common. If it exist to the same extent, it is probable that the same law would be found to prevail in regard to Female children born under such circumstances, as will be stated (§ 797) with respect to the Male;—namely, that the mortality is greater during embryonic life and early infancy, so that the preponderance is reduced. Even at birth, there is a manifest difference in the physical conditions of infants of different sexes; for, in the average of a large number, there is a decided preponderance on the side of the Males, both as to the length and the weight of the body. And it seems not improbable that this difference has a decided influence upon the greater loss of life in the act of parturition, which occurs among Male infants.

I. The *Length* of the body in fifty new-born infants of each sex, as ascertained by Quetelet,* was as follows:—

	Males.	Females.	Total.
From 16 to 17 inches† (French)	2	4	6
,, 17 to 18	8	19	27
,, 18 to 19	28	18	46
,, 19 to 20	12	8	20
,, 20 to 21	0	1	1

From these observations, the mean and the extremes of the Lengths of the *male* and *female* respectively, were calculated to be,—

	Males.	Females.
Minimum . . .	16 inches, 2 lines . . .	16 inches, 2 lines.
Mean	18 6	18 $1\frac{1}{2}$
Maximum . . .	19 8	20 6

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* "Sur l'Homme," tom. ii. p. 8.

† The French inch is about one-fifteenth more than the English.

Notwithstanding that the *maximum* is here on the side of the Female (this being an accidental result, which would probably have been otherwise, had a larger number been examined), the *average* shows a difference of 4½ lines in favour of the Male.

II. The inequality in the *Weights* of the two is even more remarkable; the observations of M. Quetelet[*] were made upon 63 male and 56 female infants.

Infants weighing from	Males.	Females.	Total.
1 to 1½ kilog.[†]	0	1	1
1½ to 2	0	1	1
2 to 2½	3	7	10
2½ to 8	13	14	27
3 to 3½	28	23	51
3½ to 4	14	7	21
4 to 4½	5	3	8

The extremes and means were as follows:—

	Males.	Females.
Minimum	2·34 kilog.	1·12
Mean	3·20	2·91
Maximum	4.50	4·25

III. The average Weight of infants of both sexes, as determined by these inquiries, is 3·05 kilog. or 6·77 lbs.; and this corresponds almost exactly with the statement of Chaussier, whose observations were made upon more than 20,000 infants. The mean obtained by him, without reference to distinction of sex, was 6·75 lbs.; the maximum being 11·3 lbs., and the minimum 3·2 lbs.[‡] The average in this country is probably rather higher; according to Dr. Joseph Clarke,[§] whose inquiries were made on 60 males and 60 females, the average of Male children is 7⅓ lbs., and that of Females 6⅔ lbs. He adds that children which at the full time weigh less than 5 lbs. rarely thrive; being generally feeble in their actions, and dying within a short time. Several instances are on record, of infants whose weight at birth exceeded 15 lbs. It appears that healthy females, living in the country, and engaged in active but not over-fatiguing occupations, have generally the largest children; and this is what might be expected *à priori*, from the superior energy of their nutritive functions.

797. There appears to be, from the first, a difference in the *Viability* (or probability of life) of Male and Female children; for, out of the total number born dead, there are 3 Males to 2 Females: this proportion gradually lessens, however, during early infancy; being about 4 to 3 during the first two months, and about 4 to 5 during the next three months; after which time the deaths are nearly in proportion to the numbers of the two sexes respectively, until the age of puberty. The viability of the two sexes continues to increase during childhood; and attains its maximum between the 13th and 14th years. For a short time after this epoch has been passed, the rate of mortality is higher in Females

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[*] Op. cit. tom. ii. p. 35.

[†] The kilogramme is equal to 2·22 lbs. avoirdupois.

[‡] These numbers have been erroneously stated in many Physiological works; owing to the difference between the French and English pound not having been allowed-for.

[§] "Philosophical Transactions," vol. lxxvi.

than in Males; but from about the age of 18 to 28, the mortality is much greater in Males, being at its maximum at 25, when the viability is only half what it is at puberty. The fact is a very striking one; and shows most forcibly that the indulgence of the passions not only weakens the health, but in a great number of instances is the cause of a very premature death. From the age of 28 to that of 50, the mortality is greater and the viability less on the side of the Female; this is what would be anticipated from the increased risk to which she is liable during the parturient period. After the age of 50, the mortality is nearly the same for both.—These facts have been expressed by Quetelet* in a form which brings them prominently before the eye (Fig. 202). The relative

FIG. 202.

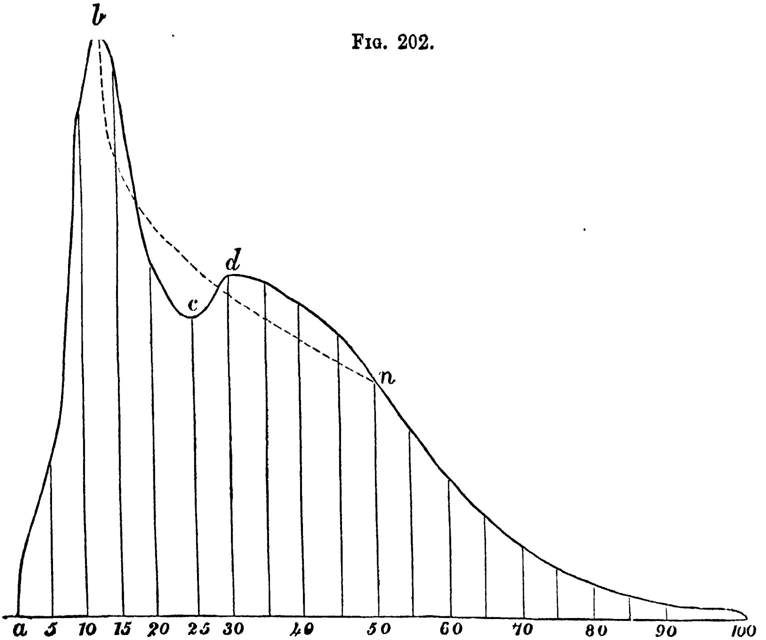

Diagram representing the *Comparative Viability of the Male and Female* at different Ages.

viability of the Male at different ages is represented by a curved line; the elevation of which indicates its degree, at the respective periods marked along the base line. The dotted line, which follows a different curve, represents the viability of the Female. Starting from *a*, the period of birth, we arrive at the maximum of viability for both at *b:* from this point, the Female curve steadily descends towards *n*, at first very rapidly, but afterwards more gradually; whilst the male curve does not quite descend so soon, but afterwards falls much lower, its minimum being *c*, which corresponds with the age of 25 years. It afterwards ascends to *d*, which is the maximum of viability subsequently to the age of puberty; this point is attained at the age of 30 years, from which period, up to 50, the probability of life is greater in the Male than in the Female. In the decline of life, there seems little or no difference for the two sexes.

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* Op. cit.

798. Similar diagrams have been constructed by Quetelet, to indicate the relative Heights and Weights of the two sexes at different ages (Fig. 203).—In regard to *Height* it may be observed, that the increase is most rapid in the first year, and that it afterwards diminishes gradually; between the ages of 5 and 16 years, the annual increase is very regular. The difference between the Height of the Male and Female, which has been already stated to present itself at birth, continues to increase during infancy and youth; it is not very decided, however, until about the 15th year, after which the growth of the Female proceeds at a much-diminished rate, whilst that of the Male continues in nearly the same degree, until about the age of 19 years. It appears, then, that the Female comes to her full development in regard to Height, earlier than does the Male. It seems probable, from the observations of Quetelet, that the full Height of the Male is not generally attained until the age of 25 years. At about the age of 50, both Male and Female undergo a diminution of their stature, which continues during the latter part of life.—The proportional *Weight* of the two sexes at different periods, corresponds pretty closely with their height. Starting from birth, the predominance then exhibited by the Male gradually increases during the first few years; but towards the period of puberty, the proportional weight of the Female increases; and at the age of 12 years, there is no difference between the two sexes in this respect. The weight of the Male, however, then increases much more rapidly than that of the Female, especially between the ages of 15 and 20 years; after the latter period, there

FIG. 203.

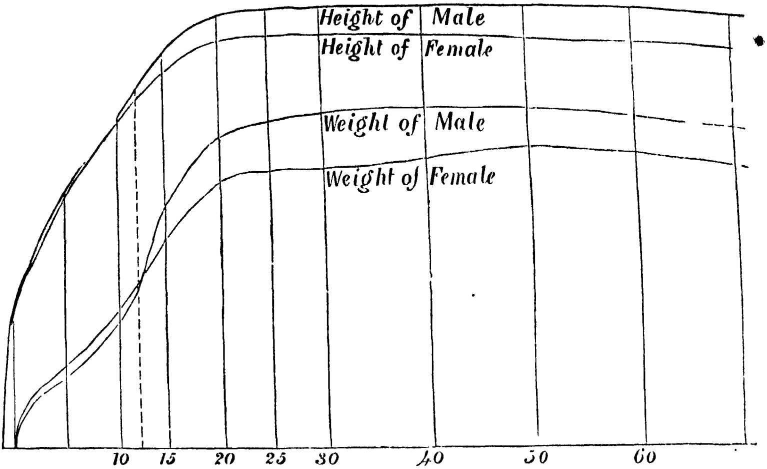

Diagram representing the *Comparative Heights and Weights* of the Male and Female at different Ages.

is no considerable increase on the side of the Male, though his maximum is not attained until the age of 40; and there is an absolute diminution on the part of the Female, whose weight remains less during nearly the whole period of child-bearing. After the termination of the parturient period, the weight of the Female again undergoes an increase, and its maximum is attained at about 50. In old age, the weight of both sexes undergoes a diminution in nearly the same degree. The average Weights of the Male and Female that have attained their full development, are 20 times those of the new-born Infants of the two sexes respectively. The Heights, on the other hand, are about 3¼ times as great.

799. The chief differences in the *Constitution* of the two sexes, manifest themselves during the period when the Generative function of each is in its greatest vigour. Many of these distinctions have been already alluded-to; but there are others of too great importance to be overlooked; and these chiefly relate to the Nervous System and its functions. There is no obvious structural difference in the Nervous System of the two sexes (putting aside the local peculiarities of its distribution to the organs of generation), save the inferior size of the Cerebral Hemispheres in the Female. This difference, which is not observed in other parts of the Encephalon, is readily accounted-for on the principles formerly stated (§ 557), when we compare the psychical character of Woman with that of Man; for there can be no doubt that —putting aside the exceptional cases which now and then occur—the *intellectual* powers of Woman are inferior to those of Man. Her *intuitive* powers are certainly greater than his; her perceptions are more acute, her apprehensions quicker; and she has a remarkable power of interpreting the feelings of others, which gives to her, not only a much more ready sympathy with them, but that facility in guiding her actions so as to be in accordance with them, which we call *tact.* This tact bears a close correspondence with the *unconscious adaptiveness* to particular ends, which we see in Instinctive actions. Notwithstanding the superiority of her perceptive faculties, her capability of sustained mental exertion is much less; and though her views are often peculiarly distinguished by the clearness and decision which result from the strength of her intuitive sense, they are generally deficient in that comprehensiveness which brings the *whole* case to be judged-of, and which is consequently necessary for their stability. With less of *volitional* power than Man possesses, she has the *emotional* in a much stronger degree. The emotions, therefore, predominate; and more frequently become the leading springs of action, than they do in Man. By their direct influence upon the bodily frame, they produce changes in the Organic functions, which far surpass in degree anything of the same kind that we ordinarily witness in Man; and they thus not unfrequently occasion symptoms of an anomalous kind, which are very perplexing to the Medical practitioner, though very interesting to the Physiological observer. But they also act as powerful motives to the Will; and, when strongly called-forth, produce a degree of vigour and determination, which is very surprising to those who have usually seen the individual under a different aspect. But this vigour, being due to the strong excitement of the Feelings, and not to any inherent strength of Intellect, is only sustained during the persistence of the motive, and fails as soon as this subsides.

The feelings of Woman, being frequently called-forth by the occurrences she witnesses around her, are naturally more disinterested than those of Man; *his* energy is more concentrated upon one object; and to this his Intellect is directed with an earnestness that too frequently either blunts his feelings, or carries them along in the same channel, thus rendering them selfish.—In regard to the inferior development of her Intellectual powers, therefore, and to the predominance of the Instinctive, Woman must be considered as ranking below Man; but in the superior purity and elevation of her Feelings, she is as highly raised above him. Her whole character, Psychical as well as Corporeal, is beautifully adapted to supply what is deficient in Man; and to elevate and refine those powers which might otherwise be directed to low and selfish objects.

5. *Of Lactation.*

800. The new-born Infant in the Human species, as in the class of Mammalia generally, is supplied with nourishment by a secretion elaborated from the blood of its maternal parent, by certain glandular organs known as the *Mammary*. The structure of these, which has been thoroughly investigated by Sir A. Cooper* and Mr. Birkett,† is extremely simple. Each gland is composed of a number of separate glandules, which are connected together by fibrous or fascial tissue, in such a manner as to allow a certain degree of mobility of its parts, one upon another, which may accommodate them to the actions of the Pectoralis muscle whereon they are bound-down; and the glandules are also connected by the ramifications of the lactiferous tubes, which intermingle with one another in such a manner as to destroy the simplicity and uniformity of their divisions, although they rarely inosculate. The *mammillary tubes*, or terminal ducts contained in the nipple, are usually about ten or twelve in number; they are straight, but of somewhat variable size; and their orifices, which are situated in the centre of the nipple, and are usually concealed by the overlapping of its sides, are narrower than the tubes themselves. At the base of the nipple, these tubes dilate into reservoirs, which extend beneath the areola and to some distance into the gland, when the breast is in a state of lactation. These are much larger in many of the lower Mammalia than in the Human female, in whom their use is to supply the immediate wants of the child when it is first applied to the breast, so that it shall not be disappointed, but shall be induced to proceed with sucking until the 'draught' be occasioned (§ 711). From each of these reservoirs commence five or six branches of the *lactiferous tubes*, each of which speedily subdivides into smaller ones; and these again divaricate, until their size is very much reduced, and their extent greatly increased (Fig. 204). These, like the reservoirs and mammillary tubes, are composed of a fibrous coat lined by a mucous membrane; the latter is highly vascular, and forms a secretion of its own, which sometimes collects in considerable quantity when the milk ceases to be produced. The smaller subdivisions of the lactiferous tubes proceed to distinct lobuli in each glandule; so that when a branch of a mammillary tube has been filled with injection, its attached lobules, if separated from

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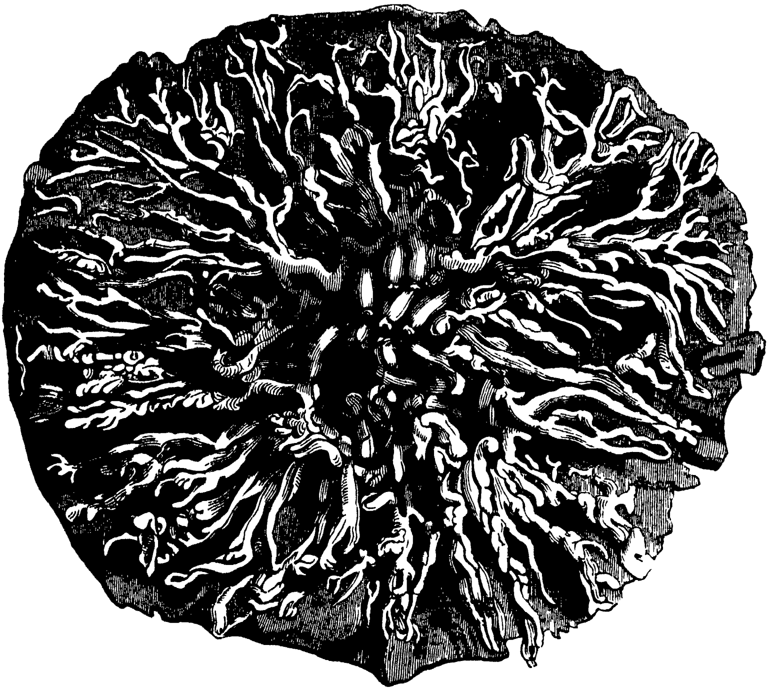
* "On the Anatomy of the Breast," 1840.

† "The Diseases of the Breast, and their Treatment," 1850.

each other by long maceration, are like a bunch of fruits clustered upon a stalk (Fig. 205). When the lactiferous tubes are pursued to their ultimate distribution, they are found to terminate in follicles, whose size, in full lactation, is that of a hole pricked in paper by the point of a very fine pin, so that, when distended with quicksilver or milk, they are just visible to the naked eye; at other times, however, the follicles do not admit of being injected, though the lactiferous tubes may have been completely filled. They are lined by a continuation of the same membrane with that which lines the ducts; and this possesses a high vascularity. The arteries which supply the glandules with blood, become very large during lactation; and their divisions spread themselves minutely on the follicles. From the blood which they convey, the milk is secreted and poured into the follicles, whence it flows into the ducts. The inner surface of the milk-follicles, in common with other glandular structures, is covered with a layer of epithelium-cells (Fig. 206), as was first observed by Prof. Goodsir; and these, being seen to contain milk-globules, may without doubt be regarded as the real agents in the secreting process. Absorbent vessels are seen to arise in large numbers in the neighbourhood

Fig 204.



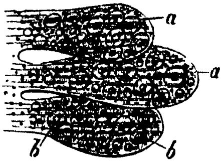
Distribution of the *Milk-ducts* in the Mamma of the Human female, during lactation; the ducts injected with wax.

of the follicles; their function appears to be, to absorb the more watery part of the milk contained in the follicles and tubes, so as to render it more nutrient than it is when first secreted; and also to relieve the distension which would occur, during the absence of the child, from the continuance of the secreting process.

FIG. 205.

Termination of portion of *Milk-duct* in a *cluster of follicles;* from a mercurial injection; enlarged four times.

FIG. 206.



Ultimate follicles of Mammary gland, with their secreting cells, *a, a,* and nuclei, *b, b.*

801. The Mammary gland may be detected at an early period of fœtal existence; being easily distinguishable from the surrounding parts by the redness of its colour and its high vascularity, especially when the whole is injected. At this period it presents no difference in the male and female; and it is not until near the period of puberty that any striking change manifests itself, the gland continuing to grow, in the one sex as in the other, in proportion to the body at large. At about the age of thirteen years, however, the enlargement of the gland commences in the Female: and by sixteen, it is greatly evolved, and some of the lactiferous tubes can be injected. At about the age of twenty, the gland attains its full size previous to lactation; but the milk-follicles cannot even then be injected from the tubes. During pregnancy, the mammæ receive a greatly-increased quantity of blood. This determination often commences very early, and produces a feeling of tenderness and distension, which is a valuable sign (where it exists in connection with others) of the commencement of gestation (§ 748). A true lacteal secretion usually commences about the third or fourth month of pregnancy, and may be obtained by pressure carefully applied. This may be turned to useful account, in diagnosing cases of concealed or doubtful pregnancy from cases of simple suppression of the catamenia; but it will not serve to distinguish true pregnancy from spurious, or from the distension of the uterus by tumours.* The vascularity of the gland continues to increase during pregnancy; and at the time of parturition its lobulated character can be distinctly felt. The follicles are not, however, developed sufficiently for injection, until lactation has commenced. After the cessation of the catamenia from age, so that pregnancy is no longer possible, the lactiferous ducts continue open, but the milk-follicles are incapable of receiving injection. The substance of the glandules gradually disappears, so that in old age only portions of the ducts remain, which are usually loaded with mucus; but the place of the glandules is commonly filled-up by adipose tissue, so that the form of the breast is preserved. Sir A. Cooper notices a curious

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* See the valuable paper by Dr. Peddie, 'On the Mammary Secretion,' in the "Edinb. Monthly Journal," Aug. 1848.

change, which he states to be almost invariable with age; namely, the ossification of the arteries of the breast, the large trunks as well as the branches, so that their calibre is greatly diminished or even obliterated.

802. The Mammary gland of the Male is a sort of miniature picture of that of the Female. It varies extremely in its magnitude; being in some persons of the size of a large pea; whilst in others it is an inch, or even two inches, in diameter. In its structure it corresponds exactly with that of the female, but is altogether formed on a smaller scale. It is composed of lobules containing follicles, from which ducts arise; and these follicles and ducts are not too minute to be injected, although with difficulty. The evolution of the gland goes-on *pari passu* with that of the body, not undergoing an increase at any particular period; it is sometimes of considerable size in old age. A fluid, which is probably mucus, may be pressed from the nipple in many persons; and this in the dead body, with even more facility than in the living. That the essential character of the gland is the same in the male as in the female, is shown by the instances, of which there are now several on record, in which infants have been suckled by men (§ 803).

803. Although the state of functional activity in the Mammary gland is usually limited to the epoch succeeding Parturition, yet this is not invariably the case; for numerous instances are on record, in which young women who have never borne children, and even old women long past the period of child-bearing, have had such a copious flow of milk as to be able to act as efficient nurses.* In these cases, the strong desire to furnish milk, and continued irritation of the nipple by the infant's mouth, seem to have furnished the stimulus requisite for the formation of the secretion; and it has been found that this is usually adequate to *restore* the secretion, after it has been intermitted for some months during the ordinary period of lactation, in consequence of disorder or debility on the part of the mother, or any other cause; so that where her condition renders it advisable that she should discontinue nursing for a time, the child may be withdrawn and the milk 'dried-up,' with a confident expectation that the secretion may be reproduced subsequently.† Dr. M'William mentions in his report of the Niger Expedition,‡ that the inhabitants of Bona Vista (Cape de Verd Island) are accustomed to provide a wet-nurse in cases of emergency, in the person of any woman who has once borne a child and is still within the age of child-bearing, by continued fomentation of the mammæ with a decoction of the leaves of the *jatropha curcas*, and by suction of the nipple.—The most curious fact, however, is that even *Men* should occasionally be able to perform the duties of nurses, and should afford an adequate supply of infantile nutriment. Several cases of this kind are upon record,§ but one of the

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* A collection of such cases is given in Dr. Dunglison's "Human Physiology," 7th edit., vol. ii. p. 513.

† See an account of M. Trousseau's experience on this point, in "L'Union Médicale," 1852, No. 7; and paper by Dr. Ballou in the "Amer. Journ. of Med. Sci.," Jan. 1852.

‡ "Medical Gazette," Jan. 1847.

§ See the case described by the Bishop of Cork, in the "Philosophical Transactions," vol. xli. p. 813: one mentioned by Sir John Franklin ("Narrative of a Journey to the Polar Sea," p. 157); and one which fell under the notice of the celebrated traveller Humboldt ("Personal Narrative," vol. iii. p. 58) most recent and authentic is that given by Dr. Dunglison.* "Professor Hall, of the University of Maryland, exhibited to his Obstetrical class, in the year 1837, a coloured man, fifty-five years of age, who had large, soft, well-formed mammæ, rather more conical than those of the female, and projecting fully seven inches from the chest; with perfect and large nipples. The glandular structure seemed to the touch to be exactly like that of the female. This man had officiated as wet-nurse for several years in the family of his mistress; and he represented that the secretion of milk was induced by applying the children entrusted to his care, to the breasts during the night. When the milk was no longer required, great difficulty was experienced in arresting the secretion. His genital organs were fully developed." Corresponding facts are also recorded of the male of several of the lower animals.

804. The secretion of *Milk* consists of Water holding in solution Sugar, various Saline ingredients, and the peculiar albuminous substance termed Casein; and having Oleaginous particles suspended in it. Its reaction is sometimes alkaline, sometimes neutral, and sometimes acid. Cows' milk is usually, and the milk of Carnivora always, acid,† from the presence of free lactic acid. The constitution of this fluid is made evident by the ordinary processes to which it is subjected in domestic economy. If it be allowed to stand for some time, exposed to the air, the greater part of the oleaginous globules come to the surface, being of less specific gravity than the fluid through which they are diffused: this is especially the case with the larger facetted globules, which have been hence distinguished as 'cream-globules.' The *cream* thus formed does not, however, consist of oily particles alone; but includes a considerable amount of casein, with the sugar and salts of the milk. These are further separated by the continued agitation of the cream; which, by rupturing the envelopes of the oil-globules, separates it into *butter*, formed by their aggregation, and *buttermilk*, containing the casein, sugar, &c. A considerable quantity of casein, however, is entangled with the oleaginous matter, and this has a tendency to decompose, so as to render the butter rancid; it may be separated by keeping the butter melted at the temperature of 180°, when the casein will fall to the bottom, leaving the butter pure and much less liable to change.—The milk, after the cream has been removed, still contains the greatest part of its casein and sugar. If it be kept long enough, a spontaneous change takes-place in its composition; the sugar is converted into lactic acid, and this coagulates the casein, precipitating it in small flakes. The same precipitation may be accomplished at any time by the addition of an acid; all the acids, however, which act upon albumen, do not precipitate casein, as will presently be pointed-out in detail; the most effectual is that contained in the dried stomach of a calf, known as *rennet*. The whey left after the curd has been separated, contains a large proportion of the saccharine and saline matter that

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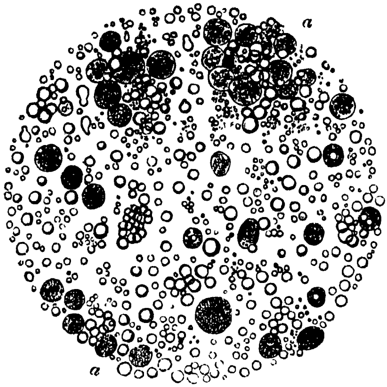
* "Human Physiology," 7th edit., vol. ii. p. 514.—Dr. Dunglison also mentions that in the winter of 1849-50, an athletic man, twenty-two years of age, presented himself at the Jefferson Medical College at Philadelphia; whose left mamma, *without any assignable cause*, had become greatly developed, and secreted milk copiously.—It may be added that a lactescent fluid, apparently presenting the character of true milk, may frequently be expressed from the mammary glands of infants. (See "Dublin Medical Press," April 17, 1850.)

† v. Gorup-Besanez, p. 388.

entered into the original composition of the milk; this may be readily separated by evaporation.

805. When Milk is examined with the Microscope, it is seen to contain a large number of particles, of irregular size and form, suspended in a somewhat turbid fluid (Fig. 207); these particles vary in size from about the 1-12,700th to the 1-3040th of an inch; and they are termed 'milk-globules.' They are not affected by the mere contact of ether or alkalies; but if these reagents are shaken with them, an immediate solution is the result. The same effect happens, if they are first treated with acetic acid. Hence it is evident, that the globules consist of oily matter, inclosed in an envelope of some kind; and an extremely delicate pellicle may, in fact, be distinguished, after the removal of the oily matter by ether, or after the globules have been ruptured and their contents pressed-out by rubbing a drop of milk between two plates of glass. No proof of the organization of this pellicle has, however, been detected; and it is probably to be regarded as the simple result of the contact of oil with albuminous matter.—Besides these milk-globules, other globules of much smaller size are seen in milk; and these present the peculiar movement which is exhibited by molecules in general. Most of them seem to consist of oily matter not inclosed in an envelope, as they are at once dissolved when the fluid is treated with ether; but, according to the statements of Donné, it would seem that a portion of them are composed of casein, suspended, not dissolved, in the fluid. In addition to the foregoing particles, there are found in the *Colostrum*, or milk secreted during the first week after delivery, large yellow granulated corpuscles (Fig. 207, *a*, *a*) which seem to be composed of a multitude of small grains aggregated together; these appear to be chiefly of a fatty nature, being for the most part soluble in ether; but traces of some adhesive matter, probably mucus, holding-together the particles, are then seen. They are considered by some as 'exudation-corpuscles,' to which they certainly bear a close resemblance; according to Reinhardt, they are transformations of the epithelial cells of the mammary ducts, the result of a sort of fatty degeneration or regressive metamorphosis consequent upon the peculiar activity of the mammary gland during pregnancy.* Lamellæ of epithelium are also found in the milk.—According to Bernard,† Colostrum contains a very large quantity of albumen, since it coagulates *en*

FIG. 207.



Microscopic appearance of *Human Milk*, with an intermixture of Colostric corpuscles at *a a*, and elsewhere.

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* See an abstract of his views in the "Edinb. Monthly Journal," Feb. 1848.

† "Leçons," vol. ii. 1859, p. 224.

masse when it is heated. At a later period none can be discovered by this method; but if sulphate of magnesia be added, all the casein and the butter will be thrown down, and on filtration, will be left on the filter with the sulphate of magnesia; the filtrate will then contain the albumen and the sugar of milk, and will coagulate on heat. All the larger globules of oil may be removed by repeated filtration; and the fluid is then nearly transparent. This, in fact, is the simplest way of separating the oleaginous from the other constituents of the milk; as but little casein then adheres to the former. The transparent fluid which has passed through the filter, contains nearly the whole amount of the casein of the milk; but even in this fluid there are found globules too minute to be kept-back by the filter, whose chemical reactions mark them as oleaginous.

806. We shall now consider the chemical characters of each of the foregoing ingredients.—The *Oleaginous* matter of milk principally consists of the ordinary components of fat; but it also contains another substance peculiar to it, designated as *butyrin*, to which the peculiar smell and taste of butter are due; this yields in saponification three volatile acids, of strong animal odour, to which Chevreul has given the names of butyric, caproic, and capric acids. These peculiar acids are not only formed when the butyrin is treated with alkalies; but are produced by the ordinary decomposition of this principle, which is favoured by time and moderate warmth.—The *Casein* of Human milk, however, is usually said to be much less precipitable by acids, than is that of the Cow; very commonly resisting the action of the mineral acids, and even that of the acetic; but being always coagulated by rennet, though the curd is long in collecting. On this point, however, there has been much discrepancy of statement, on which the experiments of Mr. Moore[*] throw some light. It appears from the results obtained by him, that Human Milk forms with most acids two sets of compounds, one of them soluble in water, the other insoluble; the latter being formed only when the quantity of acid is large in proportion to the casein. Thus, when two fluid *ounces* of Cow's milk were boiled with a single drop of nitric acid, complete coagulation of the casein at once took place: but when two fluid *drachms* of Human milk were treated in the same manner, no coagulation occurred, though the casein was at once thrown-down by a solution of ferrocyanide of potassium; the same quantity of milk, with five drops of the acid, formed a coagulum which was not very manifest until after the lapse of five hours, but was very complete, the serous fluid not being found to contain any casein by testing it with ferrocyanide of potassium; and it required ten drops of nitric acid to produce immediate coagulation. The quantity of acid necessary to produce coagulation sufficiently rapid to be immediately visible, will vary with the amount of casein present in the particular specimen of milk, 5 drops in some instances producing a coagulation as rapid as that produced by 10 drops in others. In no specimen did Mr. Moore fail to produce coagulation by adding a sufficiency of acid. Acetic acid without heat produces in Human milk a slow separation of soft flaky coagula; but, when heat is employed, a more perfect coagulation is produced by small, than by large quantitie of this acid. Rennet does not seem to act upon the casein of Huma

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[*] "Dublin Quarterly Journal of Medical Science," vol. vii. p. 280.

milk, unless an acid be also present. In several of these particulars, as well as in its small proportional amount, the Casein of Ass's milk bears a closer resemblance to that of Human milk, than does that of the Cow.—The *Sugar of Milk*, which may be obtained by evaporating whey to the consistence of a syrup, and then setting it aside to crystallize, forms four-sided prisms, whose composition is $\mathrm{C\ 24,\ H\ 19,\ O\ 19 + 5\ HO}$. In many of its properties it bears a close resemblance to Glucose or Grape sugar, into which it is readily converted by the agency of dilute sulphuric or hydrochloric acid, or by the acetic or citric acids. It is readily made to pass into the lactic and butyric fermentation, by the appropriate ferments; but is with difficulty brought to undergo the vinous fermentation. —The *Saline* matter contained in milk, appears to be nearly identical with that of the blood; with a larger proportion of the phosphates of lime and magnesia, which amount to 2 or 2½ parts in 1000. These phosphates are held in solution chiefly by the casein, which seems to have a power of combining with them even greater than that of albumen: the presence of a minute proportion of free alkali also assists their solution. A small portion of iron in the state of phosphate, together with the chlorides of potassium and sodium, may also be detected in milk.*

807. The proportion of these different constituents is liable to great variation, from several causes. Thus, the whole amount of the solid constituents may vary from 86 to 138·6 parts in 1000; the difference being partly due to individual constitution, but in great part, also, to the amount and character of the ingesta. The average seems to be between 100 and 120 parts. The following table† will serve to indicate the usual composition, as well as the ordinary variations occurring in Human milk :—

	Joly and Filhol.‡	Bödecker.	Griffith.	Doyère.	Simon.	Henry and Chevallier.
Water	874·6	882·2	875·00	873·8	861·8—914·0	879·5
Sugar of Milk . .	68	64·6	61·76	70·0	39·2— 62·4	65·0
Fat	47·5	31·0	25·41	38·0	8·0— 54·0	35·5
Albuminous Compds.	9·8	19·0	12·68	16·4	19·6— 45·0	15·2
Salts	1·1	3·2	1·55	1·8	1·6— 2·7	4·5

Milk contains about 3 per cent of its volume of Gas, having a percentage composition of 55·15 of Carbonic acid, 40·56 of Nitrogen, and 4·29 of Oxygen. It further appears from the analyses of Simon, that the proportion of the different ingredients is liable to variation according to the time which has elapsed since parturition. The quantity of Casein is at its minimum at the commencement of lactation, and then gradually rises until it attains a nearly fixed proportion. The quantity of Sugar, on the contrary, is at its maximum at first, and gradually diminishes. The amount of Butter (as appears from the wide extremes shown in the above tables) is more variable than that of any other constituent.—That some of the variations, moreover, are due to the character of the ingesta, and others to the external temperature, amount of exercise, and other circumstances affecting the individual, is proved by the inquiries of Dr. Playfair upon the Milk of the Cow. He has shown that the amount of butter depends in part upon the quantity of oily matter in the food, and in part upon the amount of exercise which the animal takes and the warmth of the atmosphere in which it is kept: exercise and cold, by increasing the respiration, eliminate part of the oily matter in the form of carbonic acid and water; whilst rest and warmth, by diminishing this drain, favour its passage into the milk. The proportion of Casein, on the other hand, is increased by exercise. Dr. Playfair's experience on this head seems to correspond with the results of common observation in Switzerland; for where the cattle pasture in very exposed situations, and are obliged to use a great deal of muscular exertion, the quantity of butter yielded by them is very small, whilst the cheese is in unusually-large proportion; but these same cattle, when stall-fed, give a large quantity of butter and very little cheese. It is quite possible, moreover, that particular breeds of cattle may yield milk of a richer quality than others. Thus Vernois and Becquerel* found that Tyrolese, Dutch, and Swiss cows gave milk containing from 7 to nearly 10 per cent of butter, with much casein and albumen; whilst the cows in the immediate neighbourhood of Paris furnished a poor milk, containing only 3·6 or 3·7 per cent of butter, and but little casein. The total amount of solid matter in the milk diminishes with age, being most abundant in nursing women of from 15 to 20 years, and smallest in those of from 35 to 40 years of age.

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* Haidlen in "Annalen der Chemie und Pharmacie," band xlv. p. 163.

† Canstatt's "Jahresbericht," 1860.

‡ Henle and Meissner's "Bericht," 1857, p. 329.

808. The change which naturally takes-place from the condition of Colostrum to that of true Milk, during the first week of lactation, is a very important one. The Colostrum has a purgative effect upon the child, which is very useful in clearing its bowels of the meconium that loads them at birth; and thus the necessity of any other purgative is generally superseded. Occasionally, however, the *colostric* character is retained by the milk during an abnormally long period; and the health of the infant is then severely affected. It is important to know that this may occur, even though the milk may present all the usual appearances of the healthy secretion; but the microscope at once detects the difference.† The *return to the character of the early milk*, which has been stated to take-place after the expiration of about twelve months, seems to indicate that Nature designs the secretion no longer to be encouraged; the mother's milk cannot then be so nutritious to the child as other food;‡ and every medical man is familiar with the injurious consequences to which she renders herself liable, by unduly prolonging lactation.§ Cases are not unfrequent, however, in which the secretion continues as long as there is a demand for it; and sometimes quite independently of this. It is the habit, among some nations, to suckle the children until they are three or four years old, and to continue doing so even though another pregnancy should supervene;‖ so that the older child is only displaced

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* "L'Union Médicale," xi. No. 26.

† See Donné, "Du Lait, et en particulier celui des Nourrices," and "Brit. and For. Med. Review," vol. vi. p. 181.

‡ On the whole subject of Infant Nutrition, the Author would strongly recommend the excellent little work of Dr. A. Combe, formerly referred-to.

§ One of these, which has particularly fallen under the Author's notice, is debility of the retina, sometimes proceeding to complete amaurosis; this, if treated in time, is most commonly relieved by discontinuance of lactation, generous diet, and quinine.

‖ See Erman's "Travels in Siberia" (translated by Cooley), vol. ii. p. 527; and the "Narrative of the United States' Exploring Expedition," vol. ii. p. 138.

by the arrival of another infant. And it seems to be chiefly among those who have thus forced the mammary gland into a state of unnaturally-persistent activity, that the spontaneous and irrepressible flow continues, after the demand for it has ceased.*

809. It is very interesting to observe that Milk contains the three classes of principles which are required for human food,—the Albuminous, the Oleaginous, and the Saccharine; and it is the only secreted fluid in which these all exist to any considerable amount. It is, therefore, the food most perfectly adapted for the young animal; and is the only single article supplied by nature, in which such a combination exists. Our artificial combinations will be suitable to replace it, just in proportion as they imitate its character; but in none of them can we advantageously dispense with milk, under some form or other. It should be remembered that the Saline ingredients of milk, especially the phosphates of lime, magnesia, and iron, have a very important function in the nutrition of the infant, affording the material for the consolidation of its bones and for the production of its red blood-corpuscles; and any fluid substituted for milk, which does not contain these, is deficient in essential constituents. It is very justly remarked by Dr. Rees,† that, of all the secreted fluids, Milk is most nearly allied in its composition to Blood.

810. The proportion of the different ingredients in the Milk of different animals, is subject to considerable variation: and this fact is of much practical importance in guiding our selection, when good Human milk cannot be conveniently obtained for the nourishment of an infant. The first point to be inquired-into, is the quantity of solid matter contained in each kind; this may be determined either by evaporation, or by the specific gravity of the fluid. The Specific Gravity of Human Milk is stated by Dr. Rees (loc. cit.) to vary between 1030 and 1035; others, however, have estimated it much lower. That of the Cow appears to be usually about the same; that of the cream, however, being 1024, and that of the skimmed-milk about 1035. The variation will in part depend (as in the case of the urine) upon the quantity of fluid ingested, and in part, it is probable, upon the manner in which the milk is drawn; for it is well known to milkers, that the last milk they obtain is much richer than that with which the udder is distended at the commencement. The quantity of solid matter obtainable from Cow's Milk by evaporation, seems to be usually considerably greater than that yielded by Human Milk; and there is also a considerable difference in the relative proportions of their ingredients, there being far more casein and less sugar in the milk of the Cow, than in that of the Human female. The following table exhibits the average proportions of the different ingredients, in the Milk of various animals from which that fluid is commonly obtained; these proportions, however, are liable to wide variations:—

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* Thus Dr. Green has published ("New York Journ. of Med. and Surg.," Sept. 1844) the case of a lady, æt. 47, the mother of four children, who had an abundant supply of milk for *twenty-seven years* previously. A period of exactly four years and a half occurred between each birth; and the children were permitted to take the breast until they were running about at play. At the time when Dr. G. wrote, she had been nine years a widow, and was obliged to have her breasts drawn daily, the secretion of milk being so copious.

† "Cyclopædia of Anatomy and Physiology," Art. 'Milk.'

	Woman.	*Cow.*	*Goat.*	*Sheep.*	*Ass.*	*Mare.*
	(Simon.)	(Simon.)	(Chevallier.)	(Chevallier.)	(Simon.)	(Luiscius.)
Water	890	860	868	856	907	888
Solids	110	140	132	144	95	112
Butter	25	38	33	42	12	8
Casein	35	68	40	45	16	16
Sugar and Extractive	48	30	53	50	65	88
Fixed Salts . . .	2	6	6	7		

It appears from this, that, whilst the milks of the Cow, Goat, and Sheep have a general correspondence with each other, those of the Ass and Mare are fluids of very dissimilar character, containing a comparatively small proportion of casein, and still less butter, but abounding in sugar. Hence it is that they are much more disposed to ferment than other milk; indeed the sugar of Mare's milk is so abundant, that the Tartars prepare from it a spirituous liquor, to which they give the name of *koumiss.* Although no milk more nearly approaches that of the Human female, in the proportion of its ingredients, than that of the Goat, its casein forms a peculiarly-dense curd, which does not suit the stomach of the infant; besides which, the milk is tainted with the peculiar odour of the animal, which is more intense if the individual be dark-coloured. The milk of the Ass, though differing in the proportion of its ingredients, seems to bear a closer approximation in properties (§ 806). The milk of the Cow will usually answer very well for the food of the infant, if care be taken to dilute it properly, according to the age of the child, and to add a little sugar. Where there is an apprehension of an early failure in the supply of Milk, the Author has found it advantageous to commence feeding the Infant once a day with this mixture, soon after the first month; the number of its meals may be progressively increased, until it becomes entirely independent of its parent, without any abrupt transition; and at the same time the proportion of water and of sugar may be diminished, in accordance with the natural change which takes place in the milk of the mother during the progress of lactation (§ 807).

811. From what has been stated of the close correspondence between the elements of the Blood and those of the Milk, it is evident that we can scarcely expect to trace the existence of the latter, as such, in the circulating fluid. To what degree the change in which their elaboration consists, is accomplished in the Mammary gland, or during the course of the circulation, there is no certain means of ascertaining. It is evident that the secretion cannot serve as the channel for the deportation of any element, the accumulation of which would be injurious to the system; since it does not occur in the Male at all, and is present in the Female at particular times only. Yet there is reason to believe that if, whilst the process is going-on, it be suddenly checked, the retention of the material in the blood, or the re-absorption of the secreted fluid, is attended with injurious consequences. Thus if, when the milk is first secreted, the child be not put to the breast, an accumulation takes place, which, if not relieved, occasions great general disturbance of the system. The narrowness of the orifices of the milk-tubes obstructs the spontaneous exit of the fluid, especially in *primiparæ;* the reservoirs and ducts become loaded; further secretion is prevented; and a state of congestion of the vessels of the gland, tending to inflammation, is induced. The accom-

panying fever is partly due, no doubt, to the local disturbance; but in part also, there seems reason to believe, to the re-absorption of the milk into the blood; this cannot but be injurious, since, although but little altered, the constitution of milk is essentially different, especially in regard to the quantity of crystallizable matter (sugar) which it contains.—Cases of the *vicarious* secretion of milk are not numerous; and in no instance is there any proof that the elements of the fluid were pre-existent in the blood. Some of the most curious are those in which it has been poured-out from a gland in the groin; but it is probable that this was in consequence of the existence of a real repetition, in that place, of the true mammary structure; this being the situation of the mammæ in many of the inferior animals, of which the homologues in Man are usually undeveloped.*

812. Of the quantity of Milk ordinarily secreted by a good Nurse, it is difficult to form a correct estimate;† since the amount which can be artificially drawn, affords no criterion of that which is secreted at the time of the 'draught' (§ 711). The quantity which can be squeezed from either breast at any one time, and which, therefore, must have been contained in its tubes and reservoirs, is about two ounces. The amount secreted is greatly influenced by the mental and physical condition of the female, and also by the quantity and character of the ingesta. In regard to the influence of the mental state upon this secretion, ample details have already been given (§§ 711, 803). With respect to the physical state most favourable to the production of an ample supply of this important fluid, it may be stated generally, that sound health, a

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* The following is a more unequivocal case of vicarious secretion; and it is peculiarly interesting as exhibiting the injurious effects of the re-absorption of the secretion, and the relief which the system experienced when it was separated from the blood by the new channel. "A lady of delicate constitution (with a predisposition to pneumonia) was prevented from suckling her child, as she desired, by the following circumstance. Soon after her delivery she had a severe fever, during which her breasts became very large and hard; the nipples were swollen and firm; and there was evidently an abundant secretion of milk; but neither the sucking of the infant, nor any artificial means, could draw a single drop of fluid from the swollen glands. It was clear that the milk-tubes were closed; and as the breasts continued to grow larger and more painful, purgatives and other means were employed to check the secretion of milk. After three days the fever somewhat diminished, and was replaced by a constant cough, which was at first dry, but soon after was followed by the expectoration of simple mucus. After this, the cough diminished in severity, and the expectoration became easy; but the sputa were no longer mucous, but were composed of a liquid, which had all the physical characters of genuine milk. This continued for fifteen days; the quantity of milk expectorated amounting to three ounces or more in the twenty-four hours. The breasts gradually diminished in size; and by the time that the expectoration ceased, they had regained their natural dimensions. The same complete obstacle to the flow of milk from the nipples recurred after the births of four children successively, with the same sequelæ. After the sixth, she had the same symptoms of fever, but this time they were not followed by bronchitis or the expectoration of milk; she had in their stead copious sweatings, which, with other severe symptoms, reduced her to a cachectic state, and terminated fatally in a fortnight." ("Bulletino delle Scienze Mediche," Apr. 1839; and "Brit. and For. Med. Review," Jan. 1840.)

† For an estimate by M. Guillot, founded on the comparative weight of the Infant before and after lactation, see "L'Union Médicale," 1852, No. 16. The total amount considered by Mons. G. to be usually drawn in the twenty-four hours, varies from 32 oz. to 64 oz. (apoth.); but his estimates are vitiated by the extraordinary frequency of the lactations observed, the infant being put to the breast from 25 to 30 times in the twenty-four hours.

vigorous but not plethoric constitution, regular habits, moderate but not fatiguing exercise, and an adequate but not excessive amount of nutritious food, furnish the conditions most required. It is seldom that stimulating liquors, which are so commonly indulged-in, are anything but prejudicial; and even where, as sometimes unquestionably happens, an improvement in the condition both of mother and infant is the immediate result of the moderate employment of them, it is questionable whether the remote effect is not of a reverse nature.* Their *modus operandi*, when they are really beneficial, seems to lie in promoting the digestive process, and in thus aiding in the appropriation of those nutritive materials which constitute the real source of the solid constituents of the milk.

813. The influence of various Medicines upon the Milk, is another important question which has not yet been sufficiently investigated. As a general rule, it appears that most soluble saline compounds pass into the milk as into other secretions; but there are many exceptions. Common salt, the sesqui-carbonate of soda, sulphate of soda, iodide of potassium, oxide of zinc, tris-nitrate of bismuth, and sesqui-oxide of iron, have been readily detected in the milk, when these substances were experimentally administered to an Ass; and ordinary experience shows that the Human infant is affected by many of these, when they are administered to the mother. The influence of mercurial medicines taken by the mother, in removing from the infant a syphilitic taint possessed by both, is also well known. The vegetable purgatives, especially castor-oil, senna, and colocynth, have little effect upon the milk; hence they are to be preferred to the saline aperients, when it is not desired to act upon the bowels of the child.

CHAPTER XVII.

OF THE DIFFERENT BRANCHES OF THE HUMAN FAMILY, AND THEIR MUTUAL RELATIONS.

1. *General Considerations.*

814. On taking a general survey of the Human race, it is natural, in the first place, that we should proceed to inquire into the evidence at present possessed of its antiquity, and into the physical and social conditions which prevailed in the most remote periods of which any information can be acquired; and secondly, that we should endeavour to ascertain whether the origin of the race is attributable to a single pair whose offspring have peopled the earth, or whether there may not have been a plurality of parents or of centres from which the singularly different nations that are now in existence have sprung. The question of the remote Antiquity of Man, though long ago suggested, has only of late years, on account of the numerous facts which seem to lend support to it, awakened a lively spirit of philosophic inquiry. When our attention has been directed to it, however, it soon appears that no subject possesses a

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* See the Author's "Physiology of Temperance and Total Abstinence," § 208.

deeper interest than the relation in which Man stands to the organic world around him,—both animal and vegetable: whether he was originally created with his corporeal powers, and the intellectual faculties to which they minister already developed to their highest extent, and capable of the greatest results that have been achieved in subsequent times; or whether he is not rather to be regarded as the crown and acmé of a long process of development commencing with far simpler organisms, which, under the protracted operation of external agents, and in accordance with the law of *continuous descent with modification through natural selection* (whereby those animals that are the strongest and best adapted for the special conditions of life present at any time, supplant, and ultimately exterminate the less perfectly constituted), has at length culminated in a creature that even now, howsoever noble in reason and infinite in faculties, yet presents a transitory condition only to some more exalted phase of existence. The facts on which this opinion rests are of various character and weight, and a few only of the more important can here be alluded-to. We have seen that in the earliest stages of the development of the embryo of the Human subject, in this respect presenting a character common to all animals, a single cell is alone discoverable, which receiving an accession of energy from the sperm-cell, and being placed under favourable conditions for the acquisition of the materials requisite for growth, soon undergoes subdivision; and that in the cellular mass thus formed a differentiation of parts takes-place, by which the various organs and tissues of the body are successively evolved. In the higher forms of the animal creation we have further seen that at certain transitory stages of development a close analogy exists with the permanent conditions of creatures occupying a lower position in the scale; and that, whilst throughout the whole a wonderful unity in the process is clearly discernible, each species presents certain characteristic features which are peculiar to itself alone. This, it is supposed, may have occurred in the history of the world. A few great types may have been originally formed, which, in the lapse of ages, owing to the action of external agents, as light, heat, and food, and to the perpetuation of accidental varieties especially adapted to these external conditions, have gradually resulted in the infinitely varied species that now surround us.* With this extraordinary similarity in the process of development throughout the whole animal kingdom, which seems very difficult to account for upon the theory of a separate creation for each species, it cannot be a matter of surprise that close bonds of alliance should be found in the adult period of life even amongst the most dissimilar creatures. The Birds, for instance, appear to be a singularly well-defined and separate group; yet the researches of Mr. Parker† have shown that in their osseous system they possess affinities with every other class of the Vertebrata; so that, whilst presenting the closest analogies to Reptiles, and especially to the Lacertilian group, they anticipate, on the one hand, various Mammalian characters, and on the other recede, as it were, below Reptiles, retaining different Ichthyic points of structure, which are not, as a rule, found in that class. And thus it has ever been found that the more closely the structure of even the most aberrant forms of animal life have been investigated, the wider have been the affinities discovered, often explaining what was previously obscure in the structure of others, whilst at the same time the more complete has been the proof that no real isolation of a species, much less of a genus or family, exists. It is indeed probable, —and this is a point on which Mr. Darwin lays great stress,—that were it possible to reproduce the entire series of forms now become extinct, a regular gradation would be presented from the lowest to the highest; and hence that, as Dr. Hooker has maintained,* we are indebted for our means of resolving plants into limitable genera and orders simply to the extinction of the forms by which they were originally connected. The reason that the intermediate links have not been discovered, is owing essentially to the imperfection of the geological record. Of that great book, comparatively few leaves have as yet been deciphered; whilst even under the most favourable circumstances, and with the largest amount of information that can be obtained from this source, it is certain that the softness of the tissues of many animals will have presented an effectual obstacle to their preservation. It is obvious that if this mode of explanation of the production of species be extended to its utmost limits, we may reach the extreme of simplicity; for it may well be said that if a few types only are needed, these may again be reduced in number to a greater and still greater degree, until at length we arrive at that which is common to all at some stage of their existence—the single nucleated cell,—a structure which comprehends the totality of the life of some animals and vegetables, and is constantly met with as the earliest stage of development of all; whilst the whole superstructure of both kingdoms may be considered to proceed from a gradual process of development and differentiation of this primary and most simple organization.

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* For a full exposition of this theory, see Darwin "On the Origin of Species by Means of Natural Selection," &c., 1859.

† See his paper 'On the Osteology of the Gallinaceous Birds and Tinnamons,' in the "Trans. of the Zoological Society" for Nov. 25, 1862.

815. By those who embrace the developmental theory, numerous facts have been recently collected, tending in the first place to prove that Man has existed for many thousands of years upon the face of the earth; and secondly, that the more remote the period at which he can be proved to have existed, the ruder, more savage and degraded, both in a social and a structural or physical point of view, was his condition. In regard to the former point, very strong evidence has recently been obtained by the discovery of Human remains intermingled with those of extinct animals, as the Mammoth, Cave Bear and woolly Rhinoceros, in the *breccias* of various caverns, as in those of Liége and Engis; whilst in other instances where no bones have been discovered, perhaps in consequence of the practice of burning the dead, almost equally unexceptionable evidence has been obtained from the discovery of works of art fashioned by Human hands, as in the flint implements found buried in the drift at Abbeville in Picardy and at St. Acheul near Amiens, and those found at Hoxne in Suffolk, and in Brixham Cave near Torquay.† In these instances the geological position of the remains, as well as the circumstance of their being accompanied by the bones of so many extinct animals, alike point to a remote antiquity. In particular, a very close investigation of those found at Moulin Quignon, near Abbeville, by

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* "Introduction to the Flora of New Zealand," 1853.

† For full information respecting which, see "The Antiquity of Man," by Sir Charles Lyell, 1863.

M. Boucher de Perthes and others, has been made by Mr. Prestwich,* who has shown that although some doubts may attach respecting the authenticity of the Human jawbone and some of the flint implements recently discovered there; yet that the genuineness of other flint implements cannot be doubted, and that the age of the gravel-beds in which they have been discovered is perfectly well determined as belonging to an early Quaternary or Postpliocene period, dating before the excavation of the valley of the Somme, and consequently to a period when the physical character of the country wore a very different aspect from that which it now presents.

816. Nor can the circumstance be disregarded, that in the oldest existent monuments, as on those of Amenophis, of Horus, and of Rhamses,† sculpture and painting, amongst the latest of the fine arts in their development, had attained to so high a degree of perfection amongst the Egyptians, that the types of the Human race there depicted may still be referred to as excellent portraitures of some of the still existing varieties—the Jew, the Mongol, and the Æthiopian being readily distinguishable. For this indicates, on the one hand, the wonderful permanence of particular types, and so far constitutes an argument against the Specific Unity of Man on the assumption that his duration upon the earth has not exceeded, as ordinarily computed, some 6000 years; whilst if we estimate the period occupied in the progress to a high degree of civilization in these old times by the rate at which it has advanced in the history of modern European nations, we find it requisite to admit the lapse of a much longer period than is usually allowed, and of a long sequence of antecedent generations. In all the nations of Western Europe, in France, in England, in Germany alike, it has taken many centuries to rear the modern fabric of civilization; and the ultimate results obtained by ancient nations, however imperfectly they may be known to us, do not appear to be of so extraordinary a nature as to lead us to attribute to them a superior, if even an equal, measure of intellectual endowments with ourselves, nor on that account to admit that their progress in mental culture may have been more rapid.‡

817. The evidence tending to show that the most ancient races of Man possessed a materially lower type of organization than those at present in existence, is not by any means sufficient to enable any general conclusions to be drawn respecting the truth of the developmental theory, or to show that there have been transitional links between the higher Apes and Man. In the most remarkable cranium yet discovered, that of the Neanderthal, which has been most carefully examined by Prof. Huxley, the forehead is indeed unusually low and retreating, the supraorbital ridges prominent, and the bones remarkably thick. Yet its cubic capacity does not appear to be materially less than that of many crania that might be selected from modern nations; and hence, as Mr. Huxley adds, the first traces of the primordial stock whence Man has proceeded need no longer be sought by those who entertain any form of the doctrine of progressive development in the

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* See "Phil. Transact.," 1860, p. 277; "Proc. of the Royal Society," vol. xii. 1862, p. 38; and "Quarterly Journal of the Geological Society," Nov. 1, 1863, vol. xix. p. 497.

† See Samuel Morton, "Crania Ægyptiaca," Philad., 1844; and the works of Champollion and Rosellini; Paul Broca, 'On the Phenomena of Hybridity in Man,' "Journal de la Physiol.," vol. iii., 1861.

‡ Sir Charles Lyell, "Antiquity of Man," p. 89.

newest tertiaries, but must be looked for in an epoch more distant from the age of the Elephas primigenius (mammals) than that is from us.

818. Many interesting facts have recently come to light, which, whilst furnishing corroborative geological evidence of the antiquity of Man, afford important means of estimating the material and social conditions of his existence in these distant epochs. The most interesting evidence upon these points is derived from the Danish Peat Mosses. These, which are of considerable depth, varying from 30 to 40 feet or more, have been the result of the slow formation of ages; and from the extraordinary preservative power which they possess, have become the receptacles or depositaries of a series of objects, from which, by a process of inductive reasoning, the most valuable conclusions can be drawn. On the surface of the soil of Denmark in the present time there flourish magnificent forests of Beech trees, numerous trunks of which are found in the superficial layers of the Peat, mingled with those of other trees, as the Alder, the Aspen, and the Birch. With these are found various instruments constructed of iron, a metal requiring a considerable amount of technical skill in its extraction, partly on account of the chemical processes to which the ores have to be subjected, and partly on account of the extremely high temperature required for its fusion or welding. These tools are accompanied by the skulls of men presenting close analogies to the present Scandinavian type, of whom, indeed, they may be considered as the early ancestors. Below the Beeches, the trunks of Oaks are found, and iron instruments cease to appear, being replaced by those of bronze. Mr. Lubbock* has adduced various considerations to show that these workers in bronze, which is composed of copper and tin, were of Eastern origin, and were perhaps allied to the modern Hindoo, with whom they agreed in the form of the head, in the practice of burning the dead, in their leading a pastoral and agricultural life, as evidenced by the associated remains of sheep, oxen, and pigs, and in using cylindrical as well as cubic dice. Still lower in the Peat the scene once more changes; the trunks of Pines now abound, and with these have been discovered crania belonging to a wholly different race—a race who were ignorant of even the simplest processes of metallurgy, and were only able to fashion, though often with great skill and ingenuity, a series of stone or flint instruments—hammer, chisel, saw, adze or dagger—and who were probably a hunting and fishing nation, burying their dead in tumuli or barrows. Additional information has been gained respecting this race, or the races coeval with them, by the investigation of the Swiss Lake Habitations, the piles supporting which have been found in the lakes of Zurich, Constance, and Geneva; and still more by careful examination of the Danish "Kitchen-middings." In the former the same succession of Iron, Bronze, and Stone eras appear to have succeeded one another; whilst the latter seem to be refuse-heaps, composed of oysters, cockles, mussels, periwinkles, and other mollusca which have been thrown out around their habitations by men of the Stone period. The crania of this race are small and round, with overhanging eyebrows. The remains of dogs and various wild animals are found in the middings, which, with the canoes, and the bones of deep-sea fish, as the cod and herring, seem to show that this ancient people lived by hunting and fishing.

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* "Natural History Review," 1861, p. 489.

819. In pursuing the second branch of our inquiry, it is apparent that amongst the various tribes of Men which people the surface of the globe, and which are separated from all other animals by the characters formerly described (Chap. II.), there are differences of a very striking and important nature. They are distinguishable from each other, not only by their language, dress, manners and customs, religious belief, and other acquired peculiarities, but by the physical conformation of their bodies; and the difference lies not merely in the colour of the skin, the nature of the hair, the form of the soft parts (such as the nose, lips, &c.), but in the shape of the skull and of other parts of the bony skeleton, which might be supposed to be less liable to variation. Now it is clearly a question of great scientific interest, as well as one that considerably affects the mode in which we regard the races that differ from our own, whether they are all of *one species*, that is, descended from the *same* or from *similar* parentage,—or whether they are to be considered as *distinct species*, the first parents of the several races having had the same differences among themselves as those which are now exhibited by their descendants.

820. In order to arrive at a just conclusion on this subject, it is necessary to take a very extensive survey of the evidence furnished by a number of different lines of inquiry. Thus, in the First place, it is right to investigate what are the discriminating structural marks, by which *species* are distinguished among other tribes of animals.—Secondly, it should be ascertained to what extent *variation* may proceed among races which are historically known to have had a common parentage, and what are the circumstances which most favour such variation.—Thirdly, the extreme variations which present themselves among the different races of Men, should be compared with those which occur among tribes of animals known to be of the same parentage; and it should be questioned, at the same time, whether the circumstances which favour the production of varieties in the latter case are in operation in the former.—Fourthly, where it is impossible to trace-back distinct races to their origin, it is to be inquired how far agreement in physiological and psychological peculiarities may be regarded as indicating specific identity, even where a considerable difference exists in bodily conformation; and this test, if it can be determined-on, has to be applied to Man.—Fifthly, it must be attempted, by a detailed examination of the varieties of the Human race themselves, to ascertain whether their differences in conformation are constant; or whether there are not such occasional manifestations, in each race, of a tendency to assume the characters of others, as to prevent any definite lines being drawn between the several tribes which together make-up the (supposed) distinct species.—An investigation so comprehensive could not be followed-out, even in the most cursory manner that would be consistent with utility, within the limits of the present work; and no more will be attempted, therefore, than an indication of the principal points of difference among the several Races of Men, and a statement of the results of inquiry into their degree of constancy in each of the principal groups which they have been thought to mark-out.*

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* The whole of this investigation has been most elaborately, and in the Author's opinion most successfully worked-out by Dr. Prichard, in his profound and philosophical Treatise on the "Physical History of Man." For a more concise view of Dr. Prichard's argument, with some additional considerations not embraced in it, the Author may refer

821. The differential characters on which those have relied, who have sought to establish the existence of a *plurality of species* among Mankind, are both Anatomico-Physiological, and Psychological. Under the former head rank the colour of the Skin, the texture of the Hair, and the conformation of the bony Skeleton, especially the Skull. The latter consist in the superiority claimed for some races over others, in Intellectual power, and in Moral and Religious capacity. The former group will be the one first considered.

822. The *Colour* of the skin exists in the Epidermis only; and it depends upon the admixture of *pigment-cells* with the ordinary epidermic cells; all the varied hues presented by the different races of men being due to the relative amount of these cells, and to the particular tint of the pigment which they form. It would be easy, by selecting well-marked specimens of each race, to make it appear that colour affords a character sufficiently distinctive for their separation; thus, for example, the fair and ruddy Saxon, the jet-black Negro, the olive Mongolian, and the copper-coloured North American, might be considered to be positively separated from each other by this character,—propagated, as it seems to be, with little or no perceptible change, from generation to generation. But although such might appear to be the clear and obvious result of a comparison of this kind, yet a more careful and comprehensive survey tends to break-down the barrier that would be thus established. For, on tracing this character through the entire family of Man, we find the isolated specimens just noticed to be connected by such a series of links, and the transition from one to the other to be so very gradual, that it is impossible to say where the lines are to be drawn between them. There is nothing here, then, which at all approaches to those fixed and definite marks, that are always held to be requisite for the establishment of specific distinctions among other tribes of animals.

823. But further, there is abundant evidence that these distinctions are far from being constantly maintained, even in any one race. For among all the principal subdivisions, *albinoism*, or the absence of pigment-cells, occasionally presents itself; so that the fair skin of the European may present itself in the offspring of the Negro or of the Red Man.* On the

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to his own Article on the 'Varieties of the Human Species,' in the "Cyclop. of Anat. and Phys.," vol. iv.—See also Dr. R. G. Latham's "Natural History of the Varieties of Man;" and his shorter Essay on the 'Varieties of the Human Species,' in Orr's "Circle of the Sciences," vol. i.

* A very curious example of *change of colour* in a Negro has been recently recorded on unquestionable authority.—The subject of it is a negro slave in Kentucky, æt. 45, who was born of black parents, and was himself perfectly black until 12 years of age. At that time a portion of the skin, an inch wide, encircling the cranium just within the edge of the hair, gradually changed to white; also the hair occupying that locality. A white spot next appeared near the inner canthus of the left eye; and from this the white colour gradually extended over the face, trunk, and extremities, until it covered the entire surface. The complete change from black to white occupied about ten years; and but for his hair, which was crisped or woolly, no one would have supposed at this time that his progenitors had offered any of the characteristics of the Negro, his skin presenting the healthy vascular appearance of that of a *fair-complexioned* European. When he was about 22 years of age, however, dark *copper-coloured* or brown spots began to appear on the face and hands; but these have remained limited to the portions of the surface exposed to light. About the time that the black colour of his skin began to disappear, he completely lost his sense of smell (§ 594, *note*); and since he has become white, he has had measles and hooping-cough a second time. (See Dr. Hutchinson's

other hand, instances are by no means rare of the unusual development of pigment-cells in individuals of the fair-skinned races; so that parts of the body are of a dark red or brown hue, or are even quite black. Such modifications may seem of little importance to the argument; since they are confined to individuals, and may be put aside as accidental. But there is ample evidence that analogous changes may take place in the course of time, which tend to produce a great variety of shades of colour, in the descendants of any one stock. Thus, in the great Indo-European family (part of the *Caucasian* race of Blumenbach), which may be unquestionably regarded as having had a common origin, we find tribes with fair complexion, yellow hair, and blue eyes,—others presenting the xanthous or olive hue,—and others decidedly black. A similar diversity may be seen among the American races, which are equally referable to one common stock; and it exists to nearly the same extent among the African nations, which appear to be similarly related to each other. It may be freely admitted that, among European colonists settled in hot climates, such changes do not present themselves within a few generations; but in many well-known instances of earlier colonization, they are very clearly manifested. Thus the wide dispersion of the Jewish nation, and their remarkable isolation (maintained by their religious observances) from the people among whom they live, render them peculiarly appropriate subjects for such observations; and we accordingly find that the brunette complexion and dark hair, which are usually regarded as characteristic of that race, are frequently superseded, in the Jews of Northern Europe, by red or brown hair and fair complexion; whilst the Jews who settled in India some centuries ago, have become as dark as the Hindoos around them.

824. The relation of the complexions of the different Races of Mankind to the climates they respectively inhabit, which is established by an extended comparative survey of both, leads to the general conclusion that the intertropical region of the earth is the principal seat of the darkest races, whilst the region remote from the tropics is that of the fairer races; and that the climates approaching the tropics are generally inhabited by nations which are of an intermediate complexion. It is important to observe, however, that no regular gradation of tint can be observed in passing from the equatorial to the polar regions. M. Paul Broca* has particularly pointed-out that the Esquimaux of Greenland, the Lapps and Finns of Europe, and the Samoyedes and Kamschatkans of Asia, all of them nations inhabiting the most northern regions of the habitable globe, present a deep olive complexion, dark straight hair, and dark eyes; being considerably deeper in hue than the Chinese, Burmese, Cochin-Chinese, and Malays, although these are situated so much nearer the equator, and are exposed to the rays of a far fiercer sun. The same conclusion is forced upon us by a survey of the various nations inhabiting the western shores of America; for if we trace them in succession from Behring's Straits to Patagonia, we shall find that under the same latitude

account of this case, in the "Amer. Journ. of Med. Sci.," Jan. 1852.—A case of partial disappearance of the black colour of the Negro's Skin was brought by Dr. Inman before the Zoological Section of the British Association at Liverpool, Sept. 1854.

* In his paper 'On Hybridity,' in M. Brown-Séquard's "Journal de la Physiologie" for 1858, p. 462. See for many analogous instances, J. Craufurd, in the "Transactions of the Ethnological Society," vol. i. p. 364.

as Norway there dwells a race whose colour is yellowish-brown, mixed with red; under that of England a perfectly white race (Vancouver's Islanders), under that of France a red race (Oregon), under that of Spain and Algeria a black race (California). From thence as far as the equator, under the same latitude as Guinea and Soudan, are races of a merely brown tint, much lighter than the inhabitants of those regions. Lastly, the races which occupy the littoral region extending from the equator to Terra del Fuego, present a brown tint, becoming lighter as the colder regions are approximated; but are suddenly succeeded, under the rigorous climate of Patagonia, by one or more blackish or altogether black races. To these observations it may be added, that high mountains, and countries of great elevation, are generally inhabited by people of a lighter colour than are those of which the level is low, such as swampy or sandy plains upon the sea-coast. These distinctions are particularly well seen in Africa, where the tropics almost exactly mark-out the limits of the black complexion of the inhabitants; and where the deepest hue is to be seen among the Negroes of the Guinea Coast, whose residence unites both the conditions just mentioned, whilst the mountainous regions in their immediate vicinity are inhabited by tribes of a much lighter aspect.

825. The nature of the *Hair* is, perhaps, one of the most permanent characteristics of different races. In regard to its colour the same statements apply as those just made with respect to the colour of the skin; the variety of hue being given by pigment-cells, which may be more or less developed under different circumstances. But it has been thought that its *texture* affords a more valid ground of distinction; and it is commonly said that the substance which grows on the head of the African races, and of some other dark-coloured tribes (chiefly inhabiting tropical climates), is *wool* and not hair. This, however, is altogether a mistake; for microscopic examination clearly demonstrates that the hair of the Negro has exactly the same structure with that of the European; and that it does not bear any resemblance to wool, save in its crispness and tendency to curl. Moreover, even this character is far from being a constant one; for, whilst Europeans are not unfrequently to be met with, whose hair is nearly as crisp as that of the Negro, there is a great variety amongst the Negro races themselves, which present every gradation from a completely-crisp (or what is termed woolly) hair, to merely curled or even flowing locks.* A similar observation holds-good in regard to the natives of the islands of the great Southern Ocean, where some individuals possess crisp hair, whilst others of the same race have it merely curled. —It is evident, then, that no characters can be drawn from the colour or texture of the hair in Man, sufficiently fixed and definite to serve for the distinction of races; and this view is borne-out by the evident influence of climate in producing changes in the hairy covering of almost every race of domestic animals; such changes often manifesting themselves in the very individuals that have been transported from one country to another, and yet more distinctly in succeeding generations.

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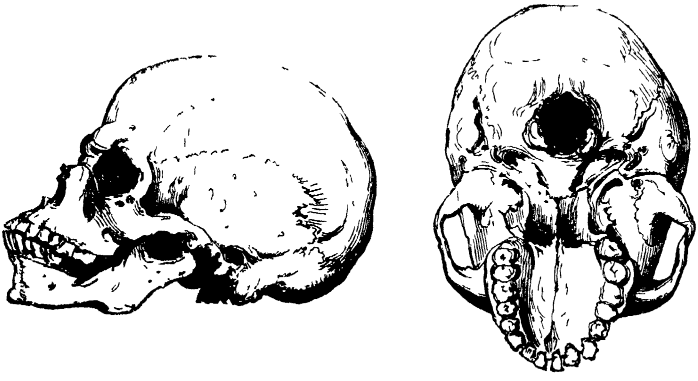
* It is a very common mistake, especially in the United States, to consider *Negro* as synonymous with *African*. So far is this from being the fact, that, as Dr. Latham justly remarks, "the true Negro area, the area occupied by men of the black skin, thick lips, and woolly hair, is exceedingly small; as small in proportion to the rest of the continent, as the area of the district of the stunted Hyperboreans is in Asia, or that of the Lapps in Europe." (See §§ 844, 845.)

826. It has been supposed that varieties in the configuration of the *Skeleton* would afford characters for the separation of the Human races, more fixed and definite than those derived from differences in the form, colour, or texture of the soft parts which clothe it: and attention has been particularly directed to the *skull* and the *pelvis*, as affording such characters. It has been generally laid-down as a fundamental principle, that all those nations which are found to resemble each other in the shape of their heads, must needs be more nearly related to each other, than they are to tribes of Men which differ from them in this particular. But if this principle be rigorously carried-out, it will tend to bring together races which inhabit parts of the globe very remote from each other, and which have no other mark of affinity whatever; whilst, on the other hand, it will often tend to separate races which every other character would lead us to bring together. It is to be remembered, moreover, that the varieties in the conformation of the skeleton, presented by the breeds of domesticated animals, are at least equal to those which are manifested in the conformation and colour of their soft parts; and we might reasonably expect, therefore, to meet with similar variations among the Human races. It is probable, however, that climate has not so much influence in producing such changes in the configuration of the body, as the peculiar habits and mode of life of the different races; and Dr. Prichard has pointed-out a very remarkable relation of this kind, in regard to the three principal types of form presented by the Skull.

827. Among the rudest tribes of Men, hunters and savage inhabitants of forests, dependent for their supply of food on the accidental produce of the soil or on the chase,—among whom are the most degraded of the African nations, and the Australian savages,—a form of head is prevalent, which is most aptly distinguished by the term *prognathous*, indicating a prolongation or forward-extension of the jaws (Fig. 208). This character is most strongly marked in the Negroes of the Gold Coast, whose skulls are usually so formed as to give the idea of lateral compression. The temporal muscles have a great extent, rising high on the parietal bones;

FIG. 208.



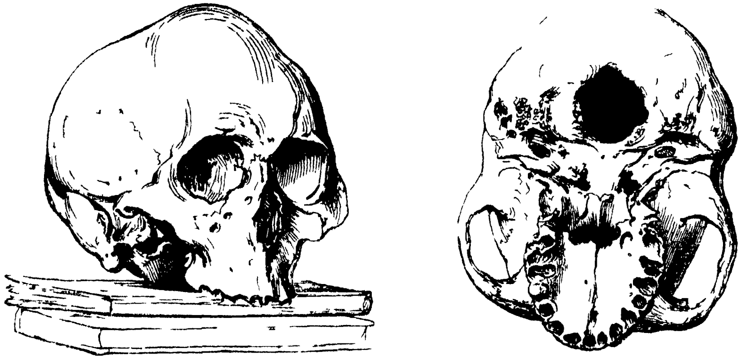
Profile and basal views of the *Prognathous Skull* of a Negro.

the cheek-bones project forward, and not outward; the upper jaw is lengthened and projects forwards, giving a similar projection to the alveolar ridge and to the teeth; and the lower jaw has somewhat of the same oblique projection, so that the upper and lower incisor teeth are set at an obtuse angle to each other, instead of being nearly in parallel planes as in the European. From the shape of the upper jaw alone would result a marked diminution in the facial angle, measured according to the method of Camper; but this diminution is far from being sufficient to approximate the Ethiopian races to the higher Apes, as some have supposed it to be (§ 24). Independently of the diminution of the facial angle resulting from the projection of the upper jaw, it is quite certain that in the typical prognathous skull there is a want of elevation of the forehead; but it does not appear that there is a corresponding diminution in the capacity of the cranial cavity, the retreating form of the forehead being partly due to the general elongation of the skull in the antero-posterior direction. Nor is it true, as stated by some, that the position of the foramen magnum in the Negro is decidedly behind that which it holds in the European, in this respect approaching that of the Apes (§ 21); since, if due allowance be made for the projection of the upper jaw, this aperture is found to have the same position in the prognathous skull as in the oval one, namely, exactly behind the transverse line bisecting the antero-posterior diameter of the base of the cranium. The prognathous skull is further remarkable for the large development of the parts connected with the organs of sense, especially those of smell and hearing. The aperture of the nostrils is very wide, and the internal space allowed for the distribution of the olfactory nerve is much larger than in most European heads; the posterior openings of the nasal cavity are not less remarkable for their width, than the anterior. The external auditory meatus is also peculiarly wide and spacious; and the orbital cavities have been thought to be of more than ordinary capacity,—but this last is by no means a constant character.

828. A second type of cranial conformation, very different from the preceding, belongs principally to the Nomadic races which wander with their herds and flocks over vast plains; and to the tribes which creep along the shores of the Icy Sea, and live partly by fishing and in part on the flesh of their reindeer. This form, designated by Dr. Prichard as the *pyramidal* (Fig. 209), is typically exhibited by various nations of Northern and Central Asia; and is seen in an exaggerated degree in the Esquimaux. Its most striking character is the lateral or outward projection of the zygoma, which is due to the form of the malar bones. These do not project forwards and downwards under the eyes, as in the prognathous skull; but take a lateral or outward direction, forming, with the zygomatic process of the temporal bone, a large rounded sweep or segment of a circle. From this, in connection with the narrowness of the forehead, it results that lines drawn from the zygomatic arches, touching the temples on either side, instead of being parallel (as in Europeans), meet over the forehead, so as to form with the basis a triangular figure. The upper part of the face being remarkably flat, the nose also being flat, and the nasal bones, as well as the space between the eyebrows, being nearly on the same plane with the cheek-bones, the triangular space bounded by these lines may be compared to one of the faces of a pyramid. The orbits are large and

deep; and the peculiar conformation of the bones which surround it, gives to the aperture of the lids an appearance of obliquity,—the inner angle seeming to be directed downwards. The whole face, instead of presenting an oval form, as in most Europeans and Africans, is of a lozenge-shape. The greater relative development of the zygomatic bones, and of the bones of the face altogether, when compared with the capacity of the cranium, indicates in the pyramidal skull a more ample extension of the organs subservient to sensation; the same effect being thus produced by lateral expansion, as by the forward extension of the facial bones in the prognathous skulls.

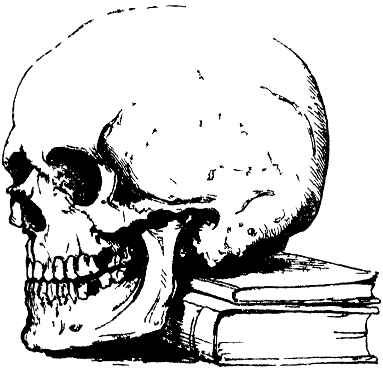
FIG. 209.



Front and basal views of the *Pyramidal Skull* of an Esquimaux

829. The most civilized races,—those which live by agriculture and the arts of cultivated life,—all the most intellectually-improved nations of Europe and Asia,—have a shape of the head which differs from both the preceding, and which may be termed *oval* or *elliptical*. This at once approves itself as a more symmetrical form; no part having an excessive prominence; whilst, on the other hand, there is nowhere an appearance of undue flattening or compression. The head is altogether of a rounder shape than in the other varieties, and the forehead is more expanded; while the maxillary bones and the zygomatic arches are so formed as to give the face an oval shape, nearly on a plane with the forehead and cheek-bones, and not projecting towards the lower part. Owing to the more perpendicular direc-

FIG 210.



Oval Skull of a European.

tion of the alveolar processes, the front teeth are fixed in planes which are nearly or quite parallel to each other. The principal features in this form of cranium are thus of a negative character; the chief positive distinction is the large development of the cranial cavity, and especially the fulness and elevation of the forehead, in proportion to the size of the face; indicating the predominance of the intellectual powers over those merely instinctive propensities which are more directly connected with sensations. Among European nations, the Greeks have probably displayed the greatest symmetry and perfection in the form of the head; but various departures may be traced towards the preceding forms, when we compare the crania of different races, and even of individuals, belonging to the same stock,—some approaching the pyramidal form of the Northern Asiatics, whilst others approximate to the prognathous type of the Negro.

830. The influence of habits of life, continued from generation to generation, upon the form of the head, is remarkably evinced by the transition from one type to another, which may be observed in nations that have undergone a change in their manners and customs, and have made an advance in civilization. Thus, to mention but one instance, the Turks at present inhabiting the Ottoman and Persian empires, are undoubtedly descended from the same stock with those nomadic races which are still spread through Central Asia (§ 842). The former, however, having conquered the countries which they now inhabit, eight centuries since, have gradually settled-down to the fixed and regular habits of the Indo-European race, and have made corresponding advances in civilization; whilst the latter have continued their wandering mode of life, and can scarcely be said to have made any decided advance during the same interval. Now the long-since-civilized Turks have undergone a complete transformation into the likeness of Europeans; whilst their nomadic relatives retain the pyramidal configuration of the skull in a very marked degree. Some have attributed this change in the physical structure of the Turkish race to the introduction of Circassian slaves into the harems of the Turks; but this could only affect the opulent and powerful amongst the race; and the great mass of the Turkish population have always intermarried among themselves. The difference of religion and manners must have kept them separate from those Greeks whom they subdued in the new Ottoman countries; as in Persia, the Tajiks, or real Persians, still remain quite distinct from their Turkish rulers, belonging to a different sect among the Mussulmans, and commonly living apart from them.—In like manner, even the Negro head and face may become assimilated to the European, by long subjection to similar influences; thus, in some of our older West Indian Colonies, it is not uncommon to meet with Negroes, the descendants of those first introduced there, who exhibit a very European physiognomy; and it has even been asserted that a Negro belonging to the Dutch portion of Guiana may be distinguished from another belonging to the British settlements, by the similarity of the features and expression of each to those which respectively characterize his masters. The effect could not be here produced by the intermixture of bloods, since this would be made apparent by alteration of colour.—But not only may the pyramidal and prognathous types be elevated towards the elliptical; the elliptical may be degraded towards

of these. Want, squalor, and ignorance, have a special tendency to induce that diminution of the cranial portion of the skull, and that increase of the facial, which characterize the prognathous type; as cannot but be observed by any one who takes an accurate and candid survey of the condition of the most degraded part of the population of the great towns of this country, but as is seen to be pre-eminently the case with regard to the lowest classes of Irish immigrants.* A certain degree of retrogression to the pyramidal type, is also to be noticed among the nomadic tribes which are to be found in every civilized community. Among these, as has been remarked by a very acute observer,† "According as they partake more or less of the purely vagabond nature, doing nothing whatsoever for their living, but moving from place to place, preying on the earnings of the more industrious portion of the community, so will the attributes of the nomade races be found more or less marked in them; and they are all more or less distinguished for their high cheek-bones and protruding jaws;" thus showing that kind of mixture of the pyramidal with the prognathous type, which is to be seen among the lowest of the Indian and Malayo-Polynesian race.

831. Next to the characters derived from the form of the head, those which are founded upon the form of the *pelvis* seem entitled to rank. These have been particularly examined by Professors Vrolik and Weber. The former was led by his examinations of this part of the skeleton, to consider that the pelvis of the Negress, and still more that of the female Hottentot, approximates to that of the Simiæ in its general configuration; especially in its length and narrowness,—the iliac bones having a more vertical position, so that the anterior spines approach one another much more closely than they do in the European; and the sacrum also being longer and narrower. On the other hand, Prof. Weber‡ concludes, from a more comprehensive survey, that no particular figure is a permanent characteristic of any one race. He groups the principal varieties which he has met-with, according to the form of the upper opening, into oval, round, four-sided, and wedge-shaped. The first of these is most frequent in the European races; the second, among the American races; the third, most common among the Mongolian nations, corresponds remarkably with their form of head; whilst the last chiefly occurs among the races of Africa, and is in like manner conformable with the oblong compressed form usually presented by their cranium. But although there are particular shapes which are most prevalent in each race, yet there are numerous individual deviations, of such a nature that every variety of form presents itself occasionally in any given race.

832. Other variations have been observed by anatomists, between the different races of Mankind, in the relative length of the bones, and in the shape of the limbs; but these also seem to have reference to the degree of civilization, and to the regularity of the supply of wholesome nutriment. It is generally to be observed that the races least improved by civilization, like the uncultivated breeds of animals, have slender,

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* See the "Dublin University Magazine," No. xlviii.

† Mr. Henry Mayhew, in "London Labour and the London Poor," p. 2.

‡ "Die Lehre von den Ur- und Racenformen der Schaedel und Becken des Menschen;" Dusseldorf, 1830.

lean, and elongated limbs; this may be especially remarked in the natives of Australia. In nearly all the less civilized races of Men, the limbs are more crooked and badly-formed than the average of those of Europeans; and this is particularly the case in the Negro, the bones of whose legs bow outwards, and whose feet are remarkably flat. It has been generally believed that the length of the fore-arm in the Negro is so much greater than in the European, as to constitute a real character of approximation to the Apes. The difference, however, is in reality extremely slight; and is not at all comparable with that which exists between the most uncultivated races of Men and the highest Apes (§ 27). And in regard to all the peculiarities here alluded-to, it is to be observed that they can only be discovered by the comparison of large numbers of one race with corresponding numbers of another; for individuals are found in every tribe, possessing the characters which distinguish the majority of the other race. Such peculiarities, therefore, are totally useless as the foundation of *specific* characters; being simply variations from the ordinary type, resulting from causes which might affect the entire race, as well as individuals.—The connection between the general form of the body, on the one hand, and the degree of civilization (involving the regular supply of nutriment) on the other, is made apparent, not merely by the improvement which we perceive in the form, development, and vigour of the frame, as we advance from the lowest to the most cultivated of the Human races; but also by the degradation that is occasionally to be met-with in particular groups of the higher tribes, which have been subjected for several generations to the influence of depressing causes. Of such degradation, occurring under circumstances that permit its successive steps to be traced, we have a remarkable example in the conversion of certain tribes of the Hottentot race into Bushmen (§ 847); and there is very strong ground for the belief that similar influences have operated at a more remote period, in the production of the peculiar characters of the Guinea-coast Negroes and Australian Bushmen.

833. Independently, however, of the obvious modifying influence of external circumstances, much allowance must be made for that *tendency to variation*, which presents itself, more or less, in all those races of animals, which possess such a constitutional capability of adaptation to changes in climate, habits of life, &c., as enables them to live and flourish under a variety of conditions. Thus we find that the offspring of any one pair of domesticated animals do not all precisely agree among themselves, or with their parents, either in bodily conformation, or in psychical character; but that *individual* differences, as they are termed, exist among them. Now, as this tendency to variation cannot be clearly traced to any influence of external circumstances, it is commonly distinguished by the term 'spontaneous;' but as there is no effect without a cause, and as the widest differences of this kind present themselves in those races which are most obviously amenable to the influence of external conditions, we seem justified in attributing them to agencies operating unostensibly upon the parents, either previously to their intercourse, or at the time of coition (§ 758), or in the female during the period of utero-gestation (§ 761). The difference between wild and domesticated animals in regard to *colour* affords a very good illustration

of this general fact; for the uniformity among the former is no less remarkable than the want of constancy among the latter; and whilst variety of colour soon gives-place to uniformity, when domesticated races return in any considerable degree towards their primitive state,* it very speedily developes itself in races which are undergoing the converse process.†

834. Now it is by taking advantage of those 'spontaneous' departures from the ordinary type, which present features of value to the breeders of domesticated animals, that *new races* are developed from time to time among these; any strongly-marked peculiarity which thus appears in only a single individual, being usually transmitted to some of its offspring, and being almost certainly perpetuated when *both* parents are distinguished by it, as happens when the products of the first procreation become capable of breeding with each other.‡—Now there can be no hesitation in admitting, that the tendency to the so-called 'spontaneous' variation prevails in the Human race to a greater degree than in any other; since we find most remarkable diversities in features, complexion, hair, and general conformation, among the offspring of the same parentage; whilst more special modifications of the ordinary type, such as the possession of six fingers on each hand and of six toes on each foot, are of no unfrequent occurrence. Under ordinary circumstances, these modifications tend to disappear as often as they occur; the free intermixture of those members of the race which possess them, with those which depart less from the ordinary type, tending to merge them in the general average. But there can be no reasonable doubt that if the same kind of segregation were practised among Mankind, which is adopted by the breeders of animals for the purpose of perpetuating a particular variety,—if, for example, the members of a six-fingered family were to intermarry exclusively with one another,—any such variety would be permanently established as a new race. Now if it be borne in mind that the influence of a scanty population, in the early ages of the Human race, by isolating different families from each other, and causing intermarriages among even the nearest relatives, would have been precisely the same with that which is now exercised by the breeders of animals, we see one reason why the varieties which *then*

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* This has been especially noticed in the dogs, horses, cattle, sheep, and hogs, introduced by the Spaniards into South America.

† Thus Mr. T. Bell informs us ("British Quadrupeds," 2nd edit., p. 203), that an Australian bitch, or dingo, in the Zoological Gardens, had a litter of puppies, the father of which was also of that breed; both parents had been taken in the wild state, both were of the uniform reddish-brown colour which belongs to the race, and the mother had never bred before; but the young, generated in confinement, and in a half-domesticated state, were all more or less spotted.

‡ See the history of the introduction of the *ancon* breed of sheep, characterized by a peculiar conformation of its limbs, in Massachusetts, given by Col. Hutchinson in the "Phil. Trans." for 1813.—A similar account has been more lately given by Prof. Owen (in a Lecture delivered before the Society of Arts, Dec. 10, 1851), respecting the recent introduction of a new breed of merino sheep, distinguished for the long, smooth, straight, and silky character of the wool, and now known as the *Mauchamp* breed.—In both instances, the breed originated in the spontaneous appearance of a male lamb possessing the peculiarities in question; from its offspring such a selection was made by the breeder, as enabled him to bring together males and females, both of which were distinguished by them; and in their progeny, the peculiarities uniformly appeared.

arose should have a much greater tendency to self-perpetuation than those which *now* occasionally present themselves. And when, too, it is borne in mind, that the change in external conditions induced by migration would thus operate not only upon the parents but upon the offspring, and would have a continual influence in so modifying the constitution of the latter that the peculiarities thus acquired by them would be transmitted in yet greater intensity to their progeny, there is no real difficulty in accounting, upon the strictest physiological principles, for the widest of those departures from one common type of conformation, which we encounter in our survey of the different Races of Mankind.*

835. Hence we are led to conclude, that, so far as regards their Anatomical structure, there is no such difference among them as would justify to the Zoologist the assertion of their distinct origin. But further, although the comparison of the structural characters of the Human races does not furnish any positive evidence of their descent from a common stock, it justifies the assertion that even if their stocks *were* originally distinct, there could have been no essential difference between them; the descendants of any one such stock being able to assume the characters of another. This, as already remarked, can be proved by historical evidence in regard to a sufficient number of tribes, to justify the same assertion with respect to others, whose languages, customs, habits of thought, &c. have an affinity strong enough to warrant us in regarding them as descendants of the same stock, whilst their physical conformation is widely different. Each principal geographical area, which is so isolated from others as to render it probable, *à priori*, that its population has extended from one centre,—such as the Continent of Africa, or America,—contains races of very diversified physical characters, whose linguistic affinities make it almost certain that they must have had a common descent; and thus, in whatever mode the types of the principal varieties are selected, they are found to be connected by so gradual a series of intermediate or transitional forms, that it is impossible to draw any such line of demarcation between them, as would be required by a soundly-judging Naturalist for the boundary of distinct species.

836. A very important confirmation of this view, is afforded by the essential agreement which exists among the different Races of Mankind in regard to their Physiological history; the variations which they present not being greater than those which we meet-with between the different individuals of any one race. Thus, we not only find the average duration of life to be the same (making allowance for circumstances which are likely to induce disease), but the various epochs of life,—such as the times of the first and second dentition, the period of puberty, the duration of pregnancy, the intervals of the catamenia, and the time of their final cessation,—present a marked general uniformity, such as does not exist among similar epochs in the lives of species that are nearly allied but yet

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* For a masterly digest of the analogical evidence furnished by the changes known to have been thus produced among domesticated animals, and of the modifications which particular tribes of Men can be shown to have undergone within the historic period, see Dr. Prichard's "Physical History of Mankind," and his "Natural History of Man;" see, also, the summary given by the Author in the "Cyclop. of Anat. and Physiol.," vol. iv. pp. 1301–1339.

unquestionably distinct. Further, the different races of Mankind are all subject to the same diseases, both sporadic, endemic, and epidemic; the only exceptions being those in which the constitution of a race has *grown to* a certain set of influences (as that of the Negro to the malaria which generate certain pernicious fevers in the European), producing an hereditary immunity in the race, which is capable of being acquired by individuals of other races, by a process of acclimatization commenced sufficiently early.*—The most important physiological test, however, of specific unity or diversity, is that furnished by the Generative process. It may be considered as a fundamental fact, alike in the Vegetable and in the Animal kingdom, that *hybrid* races originating in the sexual connection of individuals of two different *species*, do not tend to self-perpetuation; the hybrids being nearly sterile with each other, although they may propagate with either of their parent-races, in which the hybrid race will soon merge; whilst, on the other hand, if the parents be themselves *varieties* of the same species, the hybrid constitutes but another variety, and its powers of reproduction are rather increased than diminished, so that it may continue to propagate its own race, or may be used for the production of other varieties, almost *ad infinitum.* It appears that, among Plants, hybrids originating between undoubtedly distinct species, sometimes reproduce themselves for two or three generations, but do not continue beyond the fourth. Amongst animals, the limits of hybridity between parents of distinct species are more narrow, since the hybrid is totally unable to continue its race with one of its own kind;† and although it may propagate with one of its parent-species, the progeny will of course approach in character to the pure breed, and the race will speedily merge into it. In Animals, as among Plants, the mixed offsprings originating from different races within the limits of the same species generally *exceed* in vigour, and in the tendency to multiply, the parent-races from which they are produced, so as to gain-ground upon the older varieties, and gradually to supersede them. In this manner, by the *crossing* of the breeds of our domesticated animals, many new and superior varieties have been produced. The general principle is, then, that beings of distinct *species*, or descendants from stocks originally different, cannot produce a mixed race which shall possess the capability of perpetuating itself; whilst the union of *varieties* has a tendency to produce a race superior in energy and fertility to its parents.—The application of this principle to the Human races leaves no doubt with respect to their specific unity; for, as is well known, not only do all the races of Men breed freely with each other, but the mixed race is generally superior in physical development, and in tendency to rapid multiplication, to either of the parent-stocks; so that there is much reason to believe that, in many countries, the mixed race between the Aborigines and European colonizers will ultimately become the dominant power in the community. This is especially the case in India, South America, and Polynesia.

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* This view of the immunity of the Negro race from certain forms of Fever which are very fatal to Europeans, is justified, the Author believes, by all the facts known upon the subject. Much may be set down, as he is assured by Dr. Daniell, to the better adaptation of the Negro habits of life to their climate; and Europeans who exercise due caution (especially in regard to the functions of the skin), may preserve an immunity scarcely less complete. Dr. D. himself, having been taken prisoner by one of the Negro tribes at an early age, and having spent two years among them, seems to have been thoroughly acclimatized; and has subsequently passed many years on the most unhealthy parts of the coast, without experiencing any severe attacks of illness, and in the enjoyment of very good general health.—It is sometimes maintained that the Negro race possesses such a complete exemption from the Yellow Fever of the United States, as marks its specific difference; such, however, is not constantly the case, since Negroes occasionally suffer from it; and their *comparative* immunity seems fairly attributable to the constitutional peculiarity *acquired* by their African progenitors, and capable of being acquired by Europeans also.

† One or two instances have been stated to occur, in which a Mule has produced offspring from union with a similar animal; but this is certainly the extreme limit, since no one has ever maintained that the race can be continued further than the second generation, without admixture with one of the parent-species.

837. The question of *Psychical* conformity or difference among the Races of Mankind, is one which has a most direct bearing upon the question of their specific unity or diversity; but it has an importance of its own, even greater than that which it derives from this source. For, as has been argued with great justice and power,* the real Unity of Mankind does not lie in the consanguinity of a common descent, but has its basis in the participation of every race in the same moral nature, and in the community of moral rights which hence becomes the privilege of all. "This is a bond which every man feels more and more, the farther he advances in his intellectual and moral culture, and which in this development is continually placed upon higher and higher ground; so much so, that the physical relation arising from a common descent is finally lost-sight-of, in the consciousness of the higher moral obligations." It is in these obligations, that the moral *rights of men* have their foundation; and thus, "while Africans have the hearts and consciences of human beings, it could never be right to treat them as domestic cattle or as wild fowl, if it were ever so abundantly demonstrated that their race was but an improved species of ape, and ours a degenerate kind of god."—The Psychical comparison of the various Races of Mankind is really, therefore, in a practical point of view, the most important part of the whole investigation; but it has been, nevertheless, the one most imperfectly pursued, until the inquiry was taken-up by Dr. Prichard. The mass of evidence which he has accumulated on this subject, however, leaves no reasonable doubt that no more "impassable barrier" really exists between the different races with respect to this, than in regard to any of those points of ostensible diversity which have been already considered; the variations in the positive and relative development of their respective psychical powers and tendencies, not being greater, either in kind or degree, than those which present themselves between individuals of our own or of any other race, by some members of which a high intellectual and moral standard has been attained. The tests by which we recognize the claims of the outcast and degraded of our own or of any other 'highly-civilized' community, to a common humanity, are the same as those by which we should estimate the true relation of the Negro, the Bushman, or the Australian, to the cultivated European. If, on the one hand, we admit the influence of want, ignorance, and neglect, in accounting for the debasement of the savages of our own great cities,—and if we witness the same effects occurring under the same conditions among the Bushmen of Southern Africa (§ 847),—we can scarcely hesitate in admitting,

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* See the "New Quarterly Review," No. xv. p. 131; and an Article by Prof. Agassiz in the "Christian Examiner," Boston (N. E.), 1850.

that the long-continued operation of the same agencies has had much to do with the psychical as well as the physical deterioration of the Negro, Australian, and other degraded races. So, on the other hand, if we cherish the hope that the former, so far from being irreclaimable, may at least be brought-up to the standard from which they have degenerated, by means adapted to develope their intellectual faculties and to call forth the higher parts of their moral nature, no adequate reason can be assigned why the same method should not succeed with the latter, if employed with sufficient perseverance. It will be only when the effect of education, intellectual, moral, and religious, shall have been fairly tested by the experience of *many generations*, in conjunction with the influence of a perfect equality in civilization and social position, that we shall be entitled to speak of any essential and constant psychical difference between ourselves and the most degraded beings clothed in human form. All the evidence which we at present possess leads to the belief, that under a vast diversity in degree and in modes of manifestation, the same intellectual, moral, and religious *capabilities* exist in all the Races of Mankind; so that, whilst we may derive from this conformity a powerful argument for their zoological Unity as a species, we are also directly led to recognize their community of moral nature with ourselves, and to admit them to a participation in our own rights.

838. Most important assistance is afforded in the determination of the real affinities of different Races, by the study of their *Languages*. This, however, is a department of the inquiry so far beyond the limits of Physiological science, that it must be here dismissed with a bare mention of those results, to which the zealous pursuit of it by a large number of philosophic Philologists seems undoubtedly to tend.—There can be no reasonable doubt that, as a general principle, the affinities of races are more surely indicated by their languages than by their physical features; and the experienced philologist is generally able to discriminate those resemblances, which may have arisen out of the introduction of words or of modes of construction from the one into the other, by conquest, commercial intercourse, or absolute intermixture, from those which are the result of a community of origin. And thus are supplied those means of tracing the past history of races, which are seldom afforded by written records, or even (at least with any degree of certainty) by traditional information. It is to be borne in mind that the affinities of languages are indicated, not merely by verbal resemblance, but by the similarity of their modes of grammatical construction, or the methods by which the relation between different words that constitute sentences is indicated. The most positive evidence is of course afforded, when a conformity exists both in the *vocabularies* and in the *modes of construction* of two languages; but it frequently happens that although the conformity exists in regard to one of these alone, yet the evidence which it affords is perfectly satisfactory. Thus, there are many cases in which the vocabularies are so continually undergoing important changes (the want of written records not permitting them to acquire more than a traditional permanence), that their divergence becomes so great, even in the course of a few generations, as to prevent tribes which are by no means remotely descended from a common ancestry, from understanding one another; whilst yet the system of grammatical construction, which depends more

upon the grade of mental development and upon habits of thought, exhibits a remarkable permanence. Such appears to be true of the entire group of American languages; which seem, as a whole, to be legitimately referable to a common stock, notwithstanding their complete verbal diversity. On the other hand, when two languages or groups of languages differ greatly in construction, but present that kind of verbal correspondence on which the philologist feels justified in placing most reliance (namely, an essential conformity in those 'primary words' which serve to represent the universal ideas of a people in the most simple state of existence), that correspondence may be held to indicate a community of origin, if it can be proved that it has not been the result of intercourse between the two families of nations subsequently to their first divergence, and if it seems probable on other grounds that their separation took place at a period when as yet the grammatical development of both languages was in its infancy. Such appears to have been the case with certain of those groups of languages whose distinctness can be traced back historically for the longest period.*—It is evident, then, that Philological inquiry must be looked-to as one of the chief means of determining the question of radiation from a *single* centre or from *multiple* centres; and it is a remarkable fact, that the linguistic affinity and the conformity in physical characters frequently stand in a sort of complemental relation to each other, each being the strongest where the other is weakest; so that, by one or other of these links of connection, a close relationship is indicated between all those families of nations under which the several races appear to be most naturally grouped.

2. *General Survey of the Principal Varieties of the Human Species.*

839. The distribution of the Races of Mankind under five primary varieties, according to their respective types of cranial conformation, as first proposed by Blumenbach, is still so commonly received, notwithstanding the distinct proof which has been given of the fallacious nature of its basis, that it will be desirable to explain his terms, and at the same time to show how far the information subsequently acquired has tended to modify his arrangement.—The first of these varieties, which is considered to be distinguished by the possession of the *oval* or *elliptical*† type of cranial conformation, was designated *Caucasian* by Blumenbach, on two grounds; first, because he considered the Caucasian people (of whom

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* The changes, or stages of growth and development, through which all languages probably pass, have been traced in a most interesting manner by Prof. Max Müller, in his "Lectures on the Science of Language," 1861: see Lectures ii. and viii.

† Now generally termed dolichocephalic, from δολιχός, long, and κεφαλή, head; in opposition to βραχύς, short, and κεφαλή. According to Retzius, the majority of the people of *Western Europe* are dolichocephalic and orthognathic (ὀρθος, upright, and γναθος, jaw); whilst the brachycephalic is the prevalent form of the skull throughout the great extent of *Eastern Europe*. He regards the Hindoos, Arian Persians, Arabs, and Jews, with the Tungusians and Chinese, as being examples of *Asiatic* dolichocephali, the last two being prognathic (πρὸ, forwards, and γναθος, jaw), the former orthognathic; whilst the Samoiedes, Turks, Circassians, Affghans, Lascars, Tartars, Mongolians (both of Asiatic Russia and Mongolia), and Malays, are all prognathic brachycephali, and constitute the prevailing type. On the continent of Australia and in Van Diemen's Land, all the savage tribes are prognathic dolichocephali. See his 'Glance at the Present State of Ethnology with Reference to the Form of the Skull,' in the "Medico-Chir. Rev." for 1860, vol. xxv. p. 503, and vol. xxvi. p. 215.

the Georgians and Circassians are the best-known examples) as presenting its physical characters in the greatest perfection; and second, because it was supposed that the Caucasian range of mountains might be regarded as the centre or focus of the races belonging to it. Neither of these ideas, however, is correct; for whilst the oval form of cranium is presented with fully as great beauty and symmetry by the Greeks, it seems now to be almost certainly determinable by the evidence of language, that the Georgian and Circassian nations are really of Mongolian origin, and consequently have no direct relation of affinity with the other nations usually ranked as belonging to this variety; and the evidence of history and tradition, so far from pointing to the Caucasian range as the original centre of radiation of the race, accords with that of language in assigning its locality much nearer to Central Asia. It would be most desirable, therefore, that some other designation should be substituted for that given by Blumenbach; were it not that the present state of our knowledge requires the entire abandonment of his doctrine, that the races agreeing in this type of conformation are mutually connected by community of descent. For, even within the limits of Europe, we find at least two nations,—the Turks, and the Magyars or true Hungarians,—whose crania are characteristically oval, and which are yet undoubtedly of Mongolian origin; and although some allowance must be made, in regard to the change which has taken place among the former, for the influence of intermixture with other races, yet there is no reason to believe that any such influence has operated among the Magyars, whose blood seems to have been transmitted with remarkable purity from the time when they settled in Hungary about ten centuries since. In Asia, we find this type presented not merely by the Persian and other Indo-European races, but also by the Syro-Arabian, and by the larger proportion of the inhabitants of Hindostan; yet the Syro-Arabian races are more nearly related to the African stock (§ 841), than to that from which most of the present inhabitants of Europe have sprung; and there is good reason to believe that the great mass of the existing inhabitants of India are of Mongolian descent (§ 843). It will be necessary, therefore, to consider the nations which present the so-called Caucasian type of cranial conformation, under several distinct heads. No uniformity exists amongst them in regard to *colour;* for this character presents every intermediate gradation between the fair and florid tint, with light-red or auburn hair, of the Northern European, to the dusky or even black hue of the races bordering-on or lying-between the Tropics. The hair is generally long and flexible, with a tendency to curl; but considerable variety presents itself with regard to this particular. The conformation of the features approaches more or less closely to that which we are accustomed to regard as the type of beauty.

840. The first place, in a more natural distribution of the Human Races, must undoubtedly be given to that which is designated by Dr. Prichard as the *Arian,* and which is often termed the *Indo-European;* including the collective body of European nations, with the Persians,*

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* The modern Persians are a very mixed race, in which Turkish and Arab elements largely participate. The most perfect representatives of the original stock (whose purity of descent seems to have been maintained, from the time of their original migration into their present locality, by the physical obstacles which have cut them off from intercourse with their nearest neighbours) are believed to be the Kafirs of Kafiristan, a fair-skinned

Affghans, and certain other nations of the south-western portion of the Asiatic continent,* near to which their original focus appears to have been. The great bond of connection between these nations, lies in their languages; which, in spite of great diversities, present a certain community of character that is recognized by every philologist. The family which is most dissimilar to the rest (the typical Celt contrasting remarkably with the types of the Germanic group, both in physical conformation and in psychical characters,) is that formed by the *Celtic* nations; but these are undoubtedly, like the others, of Eastern origin, as was first shown by Dr. Prichard;† though they appear to have detached themselves from the common stock at an earlier period in the development of its language. The *Indo*-Germanic languages are obviously all formed upon the same base with the ancient Sanskrit, if not upon the Sanskrit itself; and they are united alike by community in many of the most important 'primary words,' and by general similarity in grammatical construction. The existing Lettish or Lithuanian dialect presents a very near approach to the original type; and the Old Prussian, a dialect spoken as late as the sixteenth century, had a still closer alliance to the ancient Zend or Median, which seems to have been a very early derivation from the Sanskrit, and which is the basis of the language now spoken in Persia.—But there is evidence that, notwithstanding the mutual affinities of the Indo-Germanic languages, every one of them has been modified by the introduction of extraneous elements: thus, in those of Western Europe, there is a considerable admixture of Celtic; whilst in others, there are traces of more barbaric tongues. In fact, there can be little doubt that Europe had an indigenous population, before the immigration of the Indo-German or even of the Celtic tribes; and of this population it seems most probable that the Lapps and Finns of Scandinavia, and the Euskarians (or Basques) of the Biscayan provinces, are but the remnant. The former of these tribes, which is undoubtedly of Mongolian origin, once extended much further south than at present; and with regard to the latter, whose nearest linguistic affinities are also with the tongues of High Asia, there is ample historical proof that they had formerly a very extensive distribution through Southern Europe. It would not seem improbable, then, that the advance of the Indo-European tribes from the south-east corner into Central Europe, separated that portion of the aboriginal (Mongolian) population which they did not absorb or destroy, into two great divisions; of which one was gradually pressed northward and eastward, so as to be restricted to Finland and Lapland; and the other southward and westward, so as to be confined at the earliest historic period to a part of the peninsula of Spain and the South of France, gradually to be driven before the successive irruptions of the Celts, Romans, Arabians, and other nations, until their scanty remnant found an enduring refuge in the

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light-haired race inhabiting the impracticable mountain-country on the watershed between the Oxus and the north-western sources of the Indus. The Tajiks of Bokhara also keep-up the ancient lineage and language, although their country is ruled by people of Turkish descent.

* The population of Hindostan has been commonly accounted as belonging to this division; but the more intimate the knowledge attained of its character and languages, the more does it lead to the conclusion that the great mass of this population is really of Mongolian descent (§ 843).

† "On the Eastern Origin of the Celtic Nations," 1831.

fastnesses of the Pyrenees.*—The Indo-Germanic race is unquestionably that which has exercised the greatest influence on the civilization of the Old World; and it seems indubitably destined to acquire a similar influence in those newly-found lands, which have been discovered by its enterprise. With scarcely an exception, as Dr. Latham has justly remarked, the nations belonging to it present an *encroaching* frontier: there being no instance of its permanent displacement by any other race, save in the case of the Arab dominion in Spain, which has long since ceased; in that of the Turkish dominion in Turkey and Asia Minor, which is evidently destined to expire at no distant period, being upheld for merely political purposes by extraneous influence; and in that of the Magyars in Hungary, who only maintain their ground through their complete assimilation to the Indo-Germanic character. It is a remarkable fact, that in most cases in which this race extends itself into countries previously tenanted by people of an entirely different type, the latter progressively decline and at last disappear before it, provided the climate be such as enables it to maintain a vigorous existence; this is pre-eminently the case in North and South America, in Australia, in New Zealand, and in many of the smaller Polynesian islands. And where the climate is less favourable to the perpetuation of the race in its purity, an intermixture with the native blood frequently gives origin to a mixed race, which possesses the developed intellect of the one, and the climatic adaptiveness of the other, and which appears likely ultimately to take the place of both.

841. The *Syro-Arabian* or *Semitic* nations agree with the preceding in general physical characters, but differ entirely in the structure of their language, and for the most part in vocabulary also, though recent researches seem to indicate that certain *roots* of the Semitic and Indo-Germanic languages have a decided affinity. It seems quite certain, however, that the linguistic affinities of the Semitic nations are rather with the *African* than with the Indo-European races; and so strong is the link of connection thus established, that by Dr. Latham they are ranked with the former under the general designation *Atlantidæ*,† whilst Mr. Norris, whose authority upon all such subjects is deservedly great, is strongly disposed (as he has himself informed the Author) to consider them an *essentially African* people.—The original seat of this race, however, is commonly reputed to have been that region of Asia which is intermediate between the countries of the Indo-European and of the Egyptian races; having as its centre the region watered by the great rivers of Mesopotamia. Several of the nations primarily constituting this group have become extinct, or nearly so; and the *Arabs*, which originally formed but one subdivision of it, have now become the dominant race, not only throughout the ancient domain of the Syro-Arabian nations, but also in Northern Africa. In the opinion of Baron Larrey, who had ample opportunities for observation, the skulls of the Arabian race furnish, at

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* This view, which was suggested by the Author in the "Brit. and For. Med. Rev.," Oct. 1847, without the knowledge that it had been elsewhere propounded, has been put forth with considerable confidence by Dr. Latham ("Varieties of Man," 1850), as having originated with Arndt and been adopted by Rask, distinguished Scandinavian ethnologists.

† See his "Varieties of Man," 1850, p. 469.

present, the most complete type of the human head; and he considered the remainder of the physical frame as equally distinguished by its superiority to that of other races of men. The different tribes of Arabs present very great diversities of colour, which are generally found to coincide with variations in climate. Thus the Shegya Arabs, and others living on the low countries bordering on the Nile, are of a dark-brown or even black hue; but even when quite jetty, they are distinguished from the Negro races by the brightness of their complexions, by the length and straightness of their hair, and by the regularity of their features. The same may be said of the wandering Arabs of Northern Africa; but the influence of climate and circumstances is still more strongly marked in some of the tribes long settled in that region, whose descent may be traced to a distinct branch of the Syro-Arabian stock, namely, the *Berber*, to which belong the Kabyles of Algiers and Tunis, the Tuaryks of Sahara, and the Guanches or ancient population of the Canary Isles. Amongst these tribes, whose affinity is indisputably traceable through their very remarkable language, every gradation may be seen, from the intense blackness of the Negro skin, to the more swarthy hue of the inhabitants of the South of Europe. It is remarkable that some of the Tuaryk inhabitants of particular Oases in the great desert, who are almost as insulated from communication with other races as are the inhabitants of islands in a wide ocean, have hair and features that approach those of the Negroes; although they speak the Berber language with such purity, as to forbid the idea of the introduction of these characters by an intermixture of races. The *Jews*, who are the only remnants now existing of the once-powerful Phœnician tribe, and who are now dispersed through nearly every country on the face of the earth, present a similar diversity; having gradually assimilated in physical characters to the nations among which they have so long resided (§ 823).

842. The second primary division of the Human family, according to the arrangement of Blumenbach, is that commonly termed *Mongolian*. The real Mongols, however, constitute but a single and not very considerable member of the group of nations associated under this designation; which is, therefore, by no means an appropriate one. The original seat of these races appears to have been the great central elevated plain of Asia, in which all the great rivers of that continent have their sources, whatever may be their subsequent direction. Taken as a whole, this division is characterized by the pyramidal form of the skull, whose antero-posterior diameter scarcely exceeds the parietal, and by the broad flat face and prominent cheek-bones; by the flattening of the nose, which is neither arched nor aquiline; by the eyes being drawn upwards at their outer angle; by the xanthous or olive complexion, which sometimes becomes fair, but frequently swarthy; by the scantiness and straightness of the hair, and deficiency of beard; and by lowness of stature. These characters, however, are exhibited in a prominent degree only in the more typical members of the group, especially those inhabiting Northern and Central Asia; and may become so greatly modified, as to cease altogether to be recognizable. Such a modification has been remarkably effected in the case of a part of the *Turkish* people, now so extensively distributed. All the most learned writers on Asiatic history are agreed in opinion, that the Turkish races are of one common stock; although at present they vary

in physical characters, to such a degree that, in some, the original type has been altogether changed. Those which still inhabit the ancient abodes of the race, and preserve their pastoral nomadic life, present the physiognomy and general characteristics which appear to have belonged to the original Turkomans; and these are decidedly referable to the so-called Mongolian type. Before the Mahommedan era, however, the Western Turks or Osmanlis had adopted more settled habits, and had made considerable progress in civilization; and their adoption of the religion of Islam incited them to still wider extension, and developed that spirit of conquest, which, during the middle ages, displayed itself with such remarkable vigour. The branches of the race, which, from their long settlement in Europe, have made the greatest progress in civilization, now exhibit in all essential particulars the physical characters of the European model; and these are particularly apparent in the conformation of the skull.—Another marked departure from the ordinary Mongolian type, is presented by the Hyperborean tribes inhabiting the borders of the Icy Sea; these have for the most part a pyramidal skull, but their complexion is swarthy and their growth is peculiarly stunted; and they form the link that connects the ordinary Mongolidæ with the Lapps and Finns of Europe on one side, and with the Esquimaux of North America on the other. The Ugrian division, which migrated towards the north-west at a very early period, planted a colony in Europe, which still tenants the northern Baltic countries, forming the races of *Finns* and *Lapps*. In the time of Tacitus, the Finns were as savage as the Lapps; but the former, during the succeeding ages, became so far civilized, as to exchange a nomadic life for one of agricultural pursuits, and have gradually assimilated with the surrounding people; whilst the Lapps, like the Siberian tribes of the same race, have ever since continued to be barbarous nomades, and have undergone no elevation in physical characters. The same division gave origin to the *Magyars* or Hungarians; a warlike and energetic people, unlike their kindred in the North; in whom a long abode in the centre of Europe has, in like manner, developed the more elevated characters, physical and mental, of the European nations.

843. The nations inhabiting the South-eastern and Southern portions of Asia, also, appear to have had their origin in the Mongolian or Central-Asiatic stock; although their features and form of skull by no means exhibit its characteristic marks, but present such departures from it, as are elsewhere observable in races that are making advances in civilization. The conformity to the Mongolian type is most decidedly shown by the nations (collectively termed *Seriform* by Dr. Latham), which inhabit China, Thibet, the Indo-Chinese peninsula, and the base of the Himalayan range; these are associated by certain linguistic peculiarities which distinguish them from all other races; that primitive condition of human speech, in which there is a total absence of inflections, indicative of the relation of the principal words to one another, being apparently preserved with less change in the tongues of these people, than in those of any other. The Chinese may be physically characterized as Mongolians softened-down; and in passing from China towards India, through the Burmese empire, there is so gradual a transition towards the

ordinary Hindoo type, that no definite line of demarcation can be anywhere drawn.—The inhabitants of the great peninsula of Hindostan have been commonly ranked (as already remarked) under the Caucasian race; both on account of their physical conformity to that type, and also because it has been considered that the basis of their languages is Sanskritic. It is certain, however, that this conclusion is incorrect with regard to a very large proportion of the existing population of India; and there is strong reason to believe that no part of it bears any real relation of affinity to the Indo-European group of nations, except such as may be derived from a slight intermixture. Thus, the *Tamulian*, which is the dominant language of *Southern* India, is undoubtedly not Sanskritic in its origin (although containing an infusion of Sanskritic words), but more closely approximates to the Seriform type; and many of the hill-tribes, in different parts of India, speak peculiar dialects, which, though mutually unintelligible, appear referable to the same stock. Now it is among this portion of the population of India, that the greatest departure presents itself from the Caucasian type of cranial formation, and the closest conformity to the Mongolian; the cheek-bones being more prominent, the hair coarse, scanty, and straight, and the nose flattened; sometimes, also, the lips are very thick, and the jaws project, showing an approximation to the prognathous type. Now in the opinion of Dr. Latham and Mr. Norris, the various dialects of *Northern* India (of which the *Hindostani* is the most extensively spoken) are to be regarded as belonging, in virtue of their fundamental nature, to the same group with those of High Asia, notwithstanding the large infusion of Sanskritic words which they contain; this infusion having been introduced at an early period by an invading branch of the Arian stock, of whose advent there is historical evidence, and whose descendants the ordinary Hindoo population have been erroneously supposed to be. According to this view, then, the influence of the Arian invasion upon the language and population of Northern India was very much akin to that of the Norman invasion upon those of England; the number of individuals of the invading race being so small in proportion to that of the indigenous population as to be speedily merged in it,—not, however, without contributing to an elevation of its physical characters; and a large number of new words having been in like manner introduced, without any essential change in the type of the original language. And thus the only distinct traces of the Arian stock are to be found in the Brahminical caste, which preserves (though with great corruption) the original Brahminical religion, and which keeps-up the Sanskrit as its classical language; it is certain, however, that this race is far from being of pure descent, having intermingled to a considerable extent with the ordinary Hindoo population. There is but little to remind us of the Mongolian type in the countenances of the Hindoos, which are often remarkable for a symmetrical beauty that only wants a more intellectual expression to render them extremely striking; some traces of it, however, may perhaps be found in the rather prominent zygomatic arches which are common amongst them; but the cranial portion of the skull presents no approach to the pyramidal type, being often very regularly elliptical. There is a remarkable difference in the colour of the different Hindoo tribes; some being nearly as dark as Negroes, others more of a copper colour, and others but little darker than the inhabitants of Southern Europe.*

844. According to the usual mode of dividing the Human family, the *Ethiopian* or *Negro* stock is made to include all the nations of Africa, to the southward of the Atlas range. But, on the one hand, the Hottentôts and Bushmen of the southern extremity constitute a group which is strongly distinguished by physical characters from the rest of the African nations; so, again, the region north of the Great Desert is mostly occupied by *Semitic* tribes (§ 841); the scattered population of the Great Desert itself is far from being Negro in many of its features; the valley of the Nile, at least in its middle and lower portions, including Egypt, Nubia, and even Abyssinia, is inhabited by a group of nations which may be designated as Nilotic, and which presents a series of gradational transitions between the Negroes and Kaffres and the Semitic races; a large portion of the area south of the Equator is occupied by the Kaffre tribes and their allies, which cannot be truly designated as Negroes: so that the true Negro area is limited to the western portion of the African continent, including the alluvial valleys of the Senegal, the Gambia, and the Niger, with a narrow strip of Central Africa, passing eastwards to the alluvial regions of the Upper Nile. Even within this area, the true Negro type of conformation, such as we see in the races which inhabit the low countries near the Slave Coast,—consisting in the combination of the prognathous form of skull with receding forehead and depressed nose, thick lips, black woolly hair, jet-black unctuous skin, and crooked legs,—is by no means universally prevalent; for many of the nations which inhabit it must be ranked as *sub-typical* Negroes; and from these the gradation in physical characters is by no means abrupt, to those African nations which possess, in a considerable degree, the attributes which we are accustomed to exclude altogether from our idea of the African race. Thus, the race of Jolofs near the Senegal, and the Guber in the interior of Sudan, have woolly hair and deep-black complexions, but fine forms and regular features of a European cast; and nearly the same may be said of the darkest of the Kaffres of Southern Africa. The Bechuana Kaffres present a still nearer approach to the European type; the complexion being of a light-brown, the hair often not woolly but merely curled, or even in long flowing ringlets, and the figure and features having much of the European character.—There is no group, in fact, which presents a more constant correspondence between external conditions and physical conformation, than that composed of the African nations. As we find the complexion becoming gradually darker, in passing from Northern to Southern Europe, thence to North Africa, thence to the borders of the Great Desert, and thence to the intertropical region where alone the dullest black is to be met with,—so do we find, on passing southwards from this, that the hue becomes gradually lighter in proportion as we proceed further from the equator, until we meet with races of comparatively fair complexions among the nations of Southern Africa. Even in the intertropical region, high elevations of the surface have the same effect as we have seen them to produce elsewhere, in lightening the

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* For many interesting particulars respecting the physical characters and habits of the wild tribes of the Veddahs of Ceylon, see a paper by J. Bailey in the "Transactions of the Ethnological Society," vol. ii. p. 278.

complexion. Thus the high parts of Senegambia, where the temperature is moderate and even cool at times, are inhabited by Fulahs of a light copper colour, whilst the nations inhabiting the lower regions around them are of true Negro blackness: and nearly on the same parallel, but at the opposite side of Africa, are the high plains of Enarea and Kaffa, of which the inhabitants are said to be fairer than the natives of Southern Europe.

845. The languages of the Negro nations, so far as they are known, appear to belong to one group; for although there is a considerable diversity in their vocabularies (arising in great part from the want of written records which would give fixity to their tongues), yet they seem to present the same grade of development and the same grammatical forms; and various proofs of their affinity with the Semitic languages have been developed, these being afforded by similarity alike of roots and of grammatical construction. The Semitic affinity of the Negro nations is further indicated in a very remarkable manner, by the existence of a variety of superstitions and usages among the Negroes of the Western coast, closely resembling those which prevail also among the Nilotic races whose Semitic relations are most clear, as well as among branches of the Semitic stock itself; and thus we seem to have adequate proof of the absence of any definite line of demarcation, in regard either to *physiological* or to *linguistic* characters, between the Negro race, and one of those which has been hitherto considered to rank among the most elevated forms of the Caucasian variety.—Nor is there anything in the *psychical* character of the Negro, which gives us a right to separate him from other races of Mankind. It is true that those races which have the Negro character in an exaggerated degree, are uniformly in the lowest stage of society, being either ferocious savages, or stupid, sensual, and indolent; such are most of the tribes along the Slave Coast. But, on the other hand, there are many Negro States, the inhabitants of which have attained a considerable degree of improvement in their social condition; such are the Ashanti, the Sulima, and the Dahomans of Western Africa, also the Guber of Central Sudan, among which a considerable degree of civilization has long existed; the physical characters of all these nations deviate considerably from the strongly-marked or exaggerated type of the Negro; and the last are perhaps the finest race of genuine Negroes on the whole continent, and present in their language the most distinct traces of original relationship to the Syro-Arabian nations. The highest civilization, and the greatest improvement in physical characters, are to be found in those African nations which have adopted the Mahommedan religion; this was introduced, three or four centuries since, into the eastern portion of Central Africa; and it appears that the same people, which were then existing in the savage condition still exhibited by the pagan nations further south, have now adopted many of the arts and institutions of civilized society, subjecting themselves to governments, practising agriculture, and dwelling in towns of considerable extent, many of which contain 10,000, and some even 30,000 inhabitants; a circumstance which implies a considerable advancement in industry, and in the resources of subsistence. This last fact affords most striking evidence of the *improvability* of the Negro races; and, taken in connection with the many instances that have presented themselves, of the advance of individuals,

under favourable circumstances, to at least the average degree of mental development among the European nations, it affords clear proof that the line of demarcation, which has been supposed to separate them intellectually and morally from the races that have attained the greatest elevation, has no more *real* existence than that which has been supposed to be justified by a difference in physical characters, and of which the fallacy has been previously demonstrated.

846. The southern portion of the African continent is inhabited by a group of nations, which (as already mentioned) recede more or less decidedly from the Negro type in physical characters, and which seem connected together by essential community of language, as branches of the stock of which the *Kaffres* may be considered the stem. In this warlike nomadic people, which inhabit the eastern parts of South Africa, to the northward of the Hottentot country, so great a departure from the ordinary Negro type presents itself, that many travellers have assigned to them a different origin. The degree of this departure, however, varies greatly in the different Kaffre tribes; for whilst some of them are black, woolly-headed, and decidedly prognathous, so as obviously to approach the modified Negroes of Congo in general aspect, others recede considerably from the typical prognathous races, both in complexion, features, and form of head, presenting a light-brown colour, a high forehead, a prominent nose, and a tall, robust, well-shaped figure. The thick lips and black frizzled hair, however, are generally retained; though the hair is sometimes of a reddish colour, and becomes flowing; and the features may present a European cast. But even among the tribes which depart most widely from the Negro type, individuals are found who present a return to it; and it is interesting to remark, that the people of Delagoa Bay, though of the Kaffre race (as indicated by their language), having been degraded by subjugation, approach the people of the Guinea Coast in their physical characters. In fact, between the most elevated Kaffre and the most degraded Negro every possible gradation of physical and psychical characters is presented to us, as we pass northwards and westwards from Kaffraria towards the Guinea Coast; and we meet with a similar transition, although not carried to so great an extent, as we pass up the eastern coast.—The languages of the Kaffres and other allied tribes are distinguished by a set of remarkable characters, which have been considered as isolating them from other African tongues. According to Dr. Latham, however, these peculiarities are not so far without precedent elsewhere as to establish the very decided line of demarcation which some have attempted to draw; and may be regarded, in fact, as resulting from the fuller development of tendencies which manifest themselves in other African languages.

847. The *Hottentot* race differs from all other South African nations, both in language and in physical conformation. Its language cannot be shown to possess distinct affinities with any other stock;* but in bodily

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* It is considered by some, that the Hottentot language is a degraded Kaffre, as the Bushman language is a degraded Hottentot; but the Author is informed by Mr. Norris, that he sees no valid ground for this assumption, the affinities of the Hottentot language being rather, in his opinion, with the languages of High Asia, although the connecting links are extremely slight. Such as they are, however, they tend to confirm an idea to the Author, some years since, by the marked reproduction of so many

structure there is a remarkable admixture of the characters of the Mongolian with those of the Negro. Thus the face presents the very wide and high cheek-bones, with the oblique eyes and flat nose, of the Northern Asiatics; at the same time that, in the somewhat prominent muzzle and thick lips, it resembles the countenance of the Negro. The complexion is of a tawny buff or fawn colour, like the black of the Negroes diluted with the olive of the Mongols. The hair is woolly, like that of the Negroes, but it grows in small tufts scattered over the surface of the scalp (like a scrubbing-brush), instead of covering it uniformly; thus resembling in its comparative scantiness that of the Northern Asiatics. It is most interesting to observe this remarkable resemblance in physical characters, between the Hottentots and the Mongolian races, in connection with the similarity that exists between the circumstances under which they respectively live; and it is not a little curious that the Hottentot, as the Mongol, should be distinguished by the extraordinary acuteness of his vision (§ 626). No two countries can be more similar than the vast steppes of Central Asia and the karroos of Southern Africa; and the proper inhabitants of each are nomadic races, wandering through deserts remarkable for the wide expansion of their surface, their scanty herbage, and the dryness of their atmosphere, and feeding upon the milk and flesh of their horses and cattle. Of the original pastoral Hottentots, however, comparatively few now remain. A large proportion of them have been gradually driven, by the encroachments of the Kaffres and of European colonists, and by internal wars with each other, to seek refuge among the inaccessible rocks and deserts of the interior; and have thus been converted from a mild, unenterprising race of shepherds, into wandering hordes of fierce, suspicious, and vindictive savages, treated as wild beasts by their fellow-men, until they become really assimilated to wild beasts in their habits and dispositions. Hence have arisen the tribes of *Bushmen* or *Bosjesmen*, which are generally regarded as presenting the most degraded and miserable condition of which the Human race is capable, and have been supposed (but erroneously) to present resemblances in physical characters to the higher Quadrumana. This transformation has taken place, under the observation of eye-witnesses, in the Koranas, a tribe of Hottentots well known to have been previously the most advanced in all the improvements which belong to pastoral life; for having been plundered by their neighbours, and driven-out into the wilderness to subsist upon wild fruits, they have adopted the habits of the Bushmen, and have become assimilated in every essential particular to that miserable tribe.—It appears, however, from the inquiries of Dr. Andrew Smith, that this process of degradation has been in operation quite independently of external agencies; nearly all the South African tribes who have made any advances in civilization being surrounded by more barbarous hordes, whose abodes are in the wildernesses of mountains and forests, and who constantly recruit their numbers by such fugitives as crime and destitution may have driven from their own more honest and more thriving com-

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Mongolian characters in the Hottentot race,—that it is the remnant of a migration from Asia, earlier than that in which the great bulk of the African nations have their origin; and that it has been driven down to the remotest corner of the continent, just as the aboriginal (Mongolian) population of south-western Europe seems to have been driven back by the Indo-European immigration (§ 840).

munities; and these people vary their mode of speech designedly, and even adopt new words, in order to make their meaning unintelligible to all but the members of their own association. This has its complete parallel in the very midst of our own or any other highly-civilized community; all our large towns containing spots nearly as inaccessible to those unacquainted with them, as are the rude caves or clefts of hills, or the burrows scooped-out of the level karroo, in which the wretched Bushman lies in wait for his prey; and these being tenanted by a people that have been well characterized as *les classes dangereuses*, which, as often as the arm of the law is paralyzed, issue-forth from the unknown deserts within which they lurk, and rival in their fierce indulgence of the most degrading passions, and in their excesses of wanton cruelty, the most terrible exhibitions of barbarian inhumanity. Such outcasts, in all nations, purposely adopt, like the Bushmen, a 'flash' language; and in their general character and usages there is a most striking parallel.*

848. The *American* nations, taken collectively, form a group which appears to have existed as a separate family of nations from a very early period in the world's history. They do not form, however, so distinct a variety, in regard to physical characters, as some anatomists have endeavoured to prove; for, although certain peculiarities have been stated to exist in the skulls of the aboriginal Americans, yet it is found on a more extensive examination, that these peculiarities are very limited in their extent,—the several nations spread over this vast continent differing from each other in physical peculiarities as much as they do from those of the Old World, so that no typical form can be made-out among them. In regard to complexion, again, it may be remarked, that although the native Americans have been commonly characterized as "red men," they are by no means invariably of a red or coppery hue, some being as fair as many European nations, others being yellow or brown, and others nearly, if not quite, as black as the Negroes of Africa; whilst, on the other hand, there are tribes equally red, and perhaps more deserving that epithet, in Africa and Polynesia. Our ordinary notion of the American races, having been chiefly founded upon the characters of those tribes of 'Indians' with whom European settlers first came into contact, proves to be no more applicable to the inhabitants of the Continent generally, than are the characters of the Negro to the population of Africa as a whole (§ 844).—In spite of all this diversity of conformation, it is believed that the structure of their languages affords a decided and clearly-marked evidence of relationship between them (§ 838). Notwithstanding their diversities in mode of life, too, there are peculiarities of mental character, as well as a number of ideas and customs derived from tradition, which seem to be common to them all; and which for the most part indicate a former elevation in the scale of civilization, that has left its traces among them even in their present depressed condition, and still distinguishes them from the sensual, volatile, and almost animalized savages, that are to be met-with in many parts of the Old Continent.—The Esquimaux have been regarded as constituting an exception to all general accounts of the physical characters of the American nations; for in the configuration of their skulls, as also in their complexion and general physiognomy, they conform to the Mongolian tribe, even presenting it in an exaggerated

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* See "London Labour and the London Poor," p. 2.

degree; whilst their wide extension along the whole northern coast of America, through the Aleutian Islands, and even to the Continent of Asia, certainly lends weight to the idea that they derive their origin from the Northern Asiatic stock. But the increased acquaintance which has been recently gained with the tribes that people the north-eastern portion of the American Continent, has clearly shown that no physical separation can be established between the Esquimaux and the Indian proper; the one form graduating so insensibly into the other, as to make the distinction between the two groups there as difficult as on the western side it is easy. Hence the existence of the Esquimaux population in this situation affords a complete link of transition between the Asiatic and the American nations, in the precise region in which the geographical relations of the two continents would lead us to expect it.

849. It now remains for us to notice the *Oceanic* races, which inhabit the vast series of islands scattered through the great ocean that stretches from Madagascar to Easter Island. There is no part of the world which affords a greater variety of local conditions than this, or which more evidently exhibits the effects of physical agencies on the organization of the human body. Moreover, it affords a case for the recognition of affinities by means of language, that possesses unusual stability; since the insulated position of the various tribes that people the remote spots of this extensive tract prevents them from exercising that influence upon each other's forms of speech, which is to be observed in the case of nations united by local proximity or by frequent intercourse. Tried by this test, it is found that the different groups of people inhabiting the greater part of these insular regions, although so widely scattered and so diverse in physical characters, are more nearly connected together than most of the families of men occupying continuous tracts of land on the great continents of the globe. A probable explanation of this remarkable affinity has been afforded by the careful investigation of the Flora and Fauna of these regions* by Dr. Hooker and Mr. Wallace; whose observations furnish strong evidence that most important and extensive geological changes have taken place since the islands scattered over that region have been peopled by their existing inhabitants. The western and eastern halves of the Indian archipelago, the former containing Sumatra and Borneo, the latter including Celebes and New Guinea, are separated at their nearest approximation by the Straits of Lombok, which are no more than fifteen miles wide: the Fauna of the former is essentially Asiatic, that of the latter essentially Australian; and there is no other intermixture between them, than such as a very limited migration across this narrow channel will readily account for. Now, the various portions of the Indian province are still connected by a vast submarine plain, which extends over the whole of the Java Sea, the Straits of Malacca, the Gulf of Siam, and the southern part of the China Sea, at a depth of not more than three hundred feet, abruptly terminating at its limits in an unfathomable ocean. An elevation of the sea-bottom to this amount, therefore, would nearly

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* See the "Introductory Essay to the Flora of New Zealand," by Dr. J. D. Hooker, 1853, and his "Flora of Australia; its Origin, Affinities, and Distribution," 1859. Also Mr. A. R. Wallace, 'On the Zoological Geography of the Malay Archipelago,' in the "Proceedings of the Linnæan Society for November, 1859; and the review of these works in the "Medico-Chir. Rev." for 1860, vol. xxv. p. 371.

double the extent of tropical Asia; and there is every probability that the continent *was* thus extended before that last great elevation of the volcanic range of Java and Sumatra took place, which (according to the general fact first brought into notice by Mr. Darwin, of an alternation of bands of elevation and depression) was coincident with the subsidence that separated those islands from Borneo on the one side, and from the continent of Asia on the other. On the other hand, the great Pacific Continent, of which New Guinea and Australia are doubtless fragments, and which (as Dr. Hooker has rendered probable by botanical considerations) once connected Australia and New Zealand with South America, seems to have extended itself as far westward as the Moluccas; and *its* submergence, producing the limitation and separation of the great islands of the South Sea, seems to have taken place before the rise of the tropical Asiatic continent. There are even indications that the tropical Indian Continent extended so near to what is now the coast of Africa, that the Isle of Bourbon and the Mauritius, perhaps even Madagascar, were outlying portions of it; and if the submergence which formed the bed of the present Indian Ocean should have taken place subsequently to the time when those countries became inhabited by Man, we have a rational explanation of the fact which has perplexed all ethnologists, and which the hypothesis of migration can scarcely be stretched far enough to account for,—that both the Fauna and the languages of Madagascar are rather Malayo-Polynesian than African in their fundamental affinities.

850. The inhabitants of Oceania seem divisible into two principal groups, which are probably to be regarded as having constituted distinct races from a very early period; these are the Malayo-Polynesian race, and the Negritos or Pelagian Negroes. The *Malayo-Polynesian* group is by far the more extensive of the two; and comprehends the inhabitants of the greater part of the Indian and Polynesian Archipelagoes, with the peninsula of Malacca (which is the centre of the Malays proper), and perhaps the inhabitants of Madagascar. These are all closely united by affinities of language. The proper Malays bear a strong general resemblance to the Mongolian races, and this resemblance is shared, in a greater or less degree, by most of the inhabitants of the Indian Archipelago. They are of a darker complexion, as might be expected from their proximity to the equator; but in this complexion, yellow is still a large ingredient. The Polynesian branch of the group presents a much wider diversity; and if it were not for the community of language, it might be thought to consist of several races, as distinct from each other as from the Malayan branch. Thus the Tahitians and Marquesans are tall and well-made; their figures combine grace and vigour; their skulls are usually remarkably symmetrical; and their physiognomy presents much of the European cast, with a very slight admixture of the features of the Negro. The complexion, especially in the females of the higher classes who are sheltered from the wind and sun, is of a clear olive or brunette, such as is common among the natives of Central and Southern Europe; and the hair, though generally black, is sometimes brown, or auburn, or even red or flaxen. Among other tribes, as the New Zealanders, and the Tonga and Friendly Islanders, there are greater diversities of conformation and hue; some being finely proportioned and vigorous, others comparatively small and feeble; some being of a copper-brown colour, others nearly

black, others olive, and others almost white. In fact, if we once admit a strongly-marked difference in complexion, features, hair, and general configuration, as establishing a claim to original distinctness of origin, we must admit the application of this hypothesis to almost every group of islands in the Pacific;—an idea, of which the essential community of language seems to afford a sufficient refutation. Among the inhabitants of Madagascar, too, all of which speak dialects of the same language, some bear a strong resemblance to the Malayan type, whilst others present approaches to that of the Negro.

851. The *Negrito* or *Pelagian-Negro* races must be regarded as a group altogether distinct from the preceding; having a marked diversity of language; and presenting, more decidedly than any of the Malayo-Polynesians, the characters of the Negro type. They form the predominating population of New Britain, New Ireland, the Louisiade and Solomon Isles, of several of the New Hebrides, and of New Caledonia; and they seem to extend westwards into the mountainous interior of the Malayan Peninsula, and into the Andaman Islands in the Bay of Bengal.* The Tasmanians, or aborigines of Van Diemen's Land, which are now almost completely exterminated, undoubtedly belonged to this group. Very little is known of them, except through the reports of the people of Malayo-Polynesian race inhabiting the same islands; but it appears that, generally speaking, they have a very inferior physical development, and lead a savage and degraded life. There is considerable diversity of physical characters among them; some approximating closely in hair, complexion, and features, to the Guinea-Coast Negroes; whilst others are of yellower tint, straight hair, and better general development. The *Papuans*, who inhabit the northern coast of New Guinea and some adjacent islands, and who are remarkable for their large bushy masses of half-woolly hair, have been supposed to constitute a distinct race; but there is little doubt that they are of hybrid descent, between the Malays and the Pelagian Negroes.—To this group we are probably to refer the *Alfourous*, or *Alforian* race, which are considered by some to be the earliest inhabitants of the greater part of the Malayan Archipelago, and to have been supplanted by the more powerful people of the preceding races, who have either extirpated them altogether, or have driven them from the coasts into the mountainous and desert parts of the interior. They are yet to be found in the central parts of the Moluccas and Philippines; and they seem to occupy most of the interior and southern portion of New Guinea, where they are termed Endamenes. They are of very dark complexion; but their hair, though black and thick, is lank. They have a peculiarly repulsive physiognomy; the nose is flattened, so as to

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* An interesting paper 'On the Mincopie Race of the Andaman Isles,' by Professor Owen, will be found in the "Transactions of the Ethnological Society" for 1863, p. 34. They appear to be amongst the most degraded of the Human species, possessing no notion of a Supreme Being, nor of a future existence, nor any sense of decency or shame; they are of diminutive size, yet the cranium is well formed, of an oval type, with rather receding forehead, and they are skilful in making knives of glass and iron cast up from wrecks. They possess considerable power of imitation, and are active in running, climbing, and swimming. They are not cannibals. Prof. Owen concludes that they are the aborigines of these islands; but remarks, that antecedent generations may have coexisted with the slow and gradual geological changes which have obliterated the place or continent of their primitive origin.

give the nostrils an almost transverse position; the cheek-bones project; the eyes are large, the teeth prominent, the lips thick, and the mouth wide. The limbs are long, slender, and misshapen. From the close resemblance in physical characters between the Endamenes of New Guinea and the aborigines of New Holland, and from the proximity between the adjacent coasts of these two islands, it may be surmised that the latter belong to the Alforian race; but too little is known of the language of either to give this inference a sufficient stability. In the degradation of their condition and manner of life, the savages of New Holland fully equal the Bushmen of South Africa; and it is scarcely possible to imagine human beings existing in a condition more nearly resembling that of brutes. But there is reason to believe, that the tribes in closest contact with European settlers are more miserable and savage than those of the interior; and even with respect to these, increasing acquaintance with their language, and a consequent improved insight into their modes of thought, tend to raise the very low estimate which has been formed and long maintained, in regard to their extreme mental degradation. The latest and most authentic statements enable us to recognize among them the same principles of a moral and intellectual nature, which, in more cultivated tribes, constitute the highest endowments of humanity; and thus to show that they are not separated by any impassable barrier, from the most civilized and elevated nations of the globe.—There are many indications, indeed, that the Negrito race is not so radically distinct from the Malayo-Polynesian, as the marked physical dissimilarity of their respective types, and the apparent want of conformity between their languages, would make it appear. For as, on the one hand, some of the subdivisions of the latter present a decided tendency towards that prognathous character and depth of complexion which are typical of the former, so among the former do we not unfrequently meet with a lighter shade of skin, a greater symmetry of skull, and a considerable improvement in form and feature. And although no very close relationship can be discovered between the Negrito and Malayo-Polynesian languages, yet it has been pointed-out by Mr. Norris that a much more decided relationship exists between the Australian and Tamulian (§ 843); and remote as this connection seems, the circumstance adds weight to the idea, that the native Australians (with other Negrito tribes) are an offset from that southern branch of the great nomadic stock of Central Asia, which seems early to have spread itself through the Indo-Chinese and the Indian Peninsulas, and to have even there shown an approximation to the prognathous type.

852. Looking, then, to the great diversity which exists among the subordinate groups of which both these divisions consist, and their tendency to mutual approximation, it cannot be shown that any sufficient reason exists for isolating them from each other; and, as already remarked (§ 850), there seems no medium between the supposition that each island had its aboriginal pair or pairs, and the doctrine that the whole of Oceania has been peopled from a common stock. Looking, again, to the very decided approximation which is presented by certain Oceanic tribes to the Mongolian type, and this in localities which, on other grounds, might be regarded as having received the first stream of migration, the possibility, to say the least, can scarcely be denied, that the

main-land furnished the original stock, which has undergone various transformations subsequently to its first dispersion; these having been the result of climatic influence and mode of life, and having been chiefly influenced as to degree by the length of time during which the transforming causes have been in operation. At any rate it may be safely affirmed, that the Oceanic races are not entitled by any distinctive physical peculiarity, to rank as a group which must have necessarily had an original stock distinct from that of the Continental nations.

CHAPTER XVIII.

OF THE MODES OF VITAL ACTIVITY CHARACTERISTIC OF DIFFERENT AGES.

853. ALTHOUGH from the time when the Human being comes into the world, to the final cessation of his corporeal existence, the various functional operations of Organic life are carried-on with ceaseless activity, whilst those of Animal life are only suspended by the intervals of repose which are needed for the renovation of their organs, yet there are very marked differences, not only in the *degree of their united activity*, but also in the *relative degrees of energy which they severally manifest*, at different epochs. These differences, taken in connection with the modifications in the size and conformation of the body with which they are in relation, mark-out the whole term of life into the various 'Ages,' which are commonly recognized as seven, namely Infancy, Childhood, Youth, Adolescence, Manhood, Decline, and Senility. For Physiological purposes, however, a less minute subdivision is equally or perhaps more appropriate; namely, the three great periods of *Growth and Development*, of *Maturity* and of *Decline*. The first comprehends the whole of that series of operations, by which the germ evolves itself at the expense of the nutriment which it appropriates from external sources, into the complete organism, possessed not merely of its full dimensions, but of its highest capacity for every kind of functional activity; this includes, therefore, the epochs of Embryonic life, Infancy, Childhood, Youth, and Adolescence, all of which are characterized by an *excess* of the *constructive* over the *destructive* changes taking-place in the organism. The second period ranges over the whole term of Manhood, in which, the organism having attained its complete development, is brought into vigorous and sustained activity; and in which it is *maintained* in a condition fitted for such activity, by the equilibrium which subsists between the operations of redintegration and of disintegration. The third period commences with the incipient failure of the bodily powers, consequent upon the *diminished* activity of the *constructive* powers, as compared with that of the changes which involve *degeneration* and *decay*; this diminution begins to manifest itself during the latter part of Middle Life, before Old age can properly be said to commence; and it continues in an increasing ratio through the whole

'decline of life,' until, the reparative powers being exhausted, Death supervenes as the necessary termination of that long succession of phenomena of which Life consists.

854. Although the organisation of the body at each epoch may be truly said to be the *resultant* of all the *material* changes which it has undergone during the preceding periods, yet it is scarcely possible to take an enlarged view of the case, without perceiving that we must look for the cause of this succession in those *dynamical* conditions, the presence of which is the distinguishing attribute of living structures. Every *constructive* act, whether this consist in Growth (§ 313) or in Development (§ 314), not merely requires *materials* for the new tissue produced, but depends upon the active operation of a *formative power*, without whose agency these materials would remain unorganized. In our examination into the source of the formative power which we see thus operating in every individual organism (CHAP. I.), we found it traceable to the *Physical* Forces to which it is subjected (Heat being the one which seems to bear most directly upon the formative operations); these forces being metamorphosed, so to speak, into the constructive force of the living body, in virtue of the peculiar endowments of *its* material substratum,—just as an Electric current transmitted through the different nerves of Sense, produces the sensory impressions which are characteristic of each respectively (§ 582); or as the same current, transmitted through one form of Inorganic matter, produces Light and Heat, through another, Chemical Change, or through another, Magnetism. But we must also recognize in the Organism at large, as well as in every integral part of it (§ 312), a certain *capacity* for growth and development,—which is the original endowment of its *germ*,—which not only determines the mode in which it shall progressively evolve itself into the fabric characteristic of its species and sex, but also shapes the peculiarities of the individual,—which serves also to bring-about the perpetual reconstruction that is needed for its continued maintenance, and is peculiarly manifested in those reparative processes which make-good losses of its substance resulting from injury or disease,—and of which the cessation, by preventing any further metamorphosis of Physical into Vital force, causes the constructive powers to fail altogether, so that the Organism is resolved-back by these very forces into the various forms of Inorganic matter at the expense of which it had been built-up.

855. Now this 'germinal capacity' is most strikingly displayed during those earliest periods of existence, in which growth and development alike are taking-place most rapidly; in fact, the further we go back in the history of intra-uterine life, the more energetic do we perceive its manifestations to be. For when we look simply at the *increase* from the minute point that constitutes the first perceptible germ, to the mature fœtus of 6 or 7 lbs. weight, we see that at no other period of existence can that increase be compared in its rate, with that which presents itself during the nine months that follow conception; and if we go more into detail, we find that it is yet more remarkable in the earlier than in the later months (§ 857). So, again, it is in the first few weeks of embryonic life, that the foundation is laid of most of its permanent *organs*, in the midst of an apparently-homogeneous mass of cells; whilst in the succeeding weeks, these rudiments are evolved into the semblance of the forms

they are subsequently to present, and a differentiation of *tissues* begins to show itself in their several parts; so that the developmental process is so far advanced at little more than half the term of gestation, that the fœtus may even then, under favourable circumstances, maintain an independent existence (§ 754). The rate of increase becomes progressively slower during the advance from infancy to maturity; and the energy of the developmental process is comparatively enfeebled, being limited to the perfecting of structures whose foundations had been previously laid, and in no instance manifesting itself normally in the evolution of a new part or organ. Now as there is no limit (in the well-nourished individual) to the supply of Food and Warmth, it follows that this gradual decline of formative activity must be due to a diminution of the *capacity* for that activity, inherent in the organism itself; and this diminution is still more strongly marked by that entire cessation, both of increase, and of further developmental changes, which constitutes the termination of the first period. For the organism which has attained that stage of its existence, has so far lost the formative capacity which characterized its earlier years, that, however copious the supply of food, however abundant the generation of heat, it can thenceforth do no more than *maintain* its normal condition, and can effect this for only a limited term of years. It seems a necessary sequence of this series of phenomena, that the time should come, when, after a period of gradual decline, the germinal capacity of the organism should be so much reduced as no longer to suffice for the maintenance of its own integrity; and whenever such is the case, the termination of its existence as a living body must be the necessary result. Hence we find that there is a natural limit, not only to the size and development of the organism, but also to the duration of its life. And although that limit, in each case, is subject to variation amongst *individuals*, partly in consequence of diversity of external conditions, but partly (it may be surmised) through differences in the measure of germinal capacity possessed by each, yet there is a limit also to these variations, so that the character of the *species* is never departed-from.

856. *Period of Growth and Development.*—The general history of the first part of this period, that of Embryonic existence, has already been so fully given, that it is only necessary here to remark briefly in regard to the character of its vital operations, that the whole nisus of its activity is directed rather to the performance of the *vegetative* or *organic* than to that of the *animal* functions; the action of the heart, and the occasional reflex movements of the limbs, being its only manifestations of nervo-muscular power. And thus it seems to be that the formative capacity is greater during embryonic life, than at any subsequent period, and greater in its earlier than in its later stages; so that we have not only evidence of an extraordinary power of regenerating parts which have been lost by disease or accident, as seen in attempts at the reproduction of entire limbs after their 'spontaneous amputation' (§ 343); but there is also not unfrequently an absolute excess of productive power, as shown in the development of supernumerary organs, which may even proceed to the extent of the complete duplication of the entire body, by the early subdivision of the embryonic structure into two independent halves (§ 339).—It is to be noticed, also, that the embryo derives its supply not merely of food but also of *heat*, from its maternal parent; and it is probably owing

especially to the constancy with which this force operates, that the period of embryonic development is so uniform in Man (as in warm-blooded Animals generally), by comparison with the corresponding developmental periods in Plants and cold-blooded Animals, these being entirely determined by the degree of heat to which the embryoes are subjected.

857. It is frequently of great importance, both to the Practitioner and to the Medical Jurist, to be able to determine the *age* of a Fœtus from the physical characters which it presents; and the following table has been framed by Devergie[*] in order to facilitate such determination. It is to be remarked, however, that the *absolute length* and *weight* of the Embryo are much less safe criteria than its *degree of development*, as indicated by the relative evolution of the several parts which make their appearance successively. Thus it is very possible for one child born at the full time, to *weigh* less than another born at 8 or even at 7 months; its *length*, too, may be inferior: and even the position of the *middle point* of the body is not, taken alone, a safe criterion, since it is liable to variation in individuals.[†]

Embryo 3 to 4 weeks.—It has the form of a serpent;—its length from 3 to 5 lines;—its head indicated by a swelling;—its caudal extremity (in which is seen a white line, indicating the continuation of the medulla spinalis), slender, and terminating in the umbilical cord;—the mouth indicated by a cleft, the eyes by two black points;—members begin to appear as nipple-like protuberances;—liver occupies the whole abdomen;—the bladder is very large;—the chorion is villous, but its villosities are still diffused over the whole surface.

Embryo of 6 weeks.—Its length from 7 to 10 lines;—its weight from 40 to 75 grains;—face distinct from cranium;—aperture of nose, mouth, eyes, and ears perceptible;—head distinct from thorax;—hands and fore-arms in the middle of the length; fingers distinct;—legs and feet situated near the anus;—clavicle and maxillary bone present a point of ossification;—distinct umbilicus for attachment of cord, which at that time consists of the omphalo-meseraic vessels, of a portion of the urachus, of a part of the intestinal tube, and of filaments which represent the umbilical vessels;—the placenta begins to be formed;—the chorion still separated from the amnion;—the umbilical vesicle very large.

Embryo of 2 months.—Length from 16 to 19 lines;—weight from 150 to 300 grains;—elbows and arms detached from the trunk;—heels and knees also isolated;—rudiments of the nose and of the lips; palpebral circle beginning to show itself;—clitoris or penis apparent;—anus marked by a dark spot;—rudiments of lungs, spleen, and supra-renal capsules;—cæcum placed behind the umbilicus;—digestive canal withdrawn into the abdomen;—urachus visible;—osseous points in the frontal bone and in the ribs;—chorion commencing to touch the amnion at the point opposite the insertion of the placenta;—placenta begins to assume its regular form;—umbilical vessels commence twisting.

Embryo of 3 months.—Length from 2 to 2½ inches;—weight from 1 oz. to 1½ oz. (Troy);—head voluminous;—eyelids in contact by their free margin;—membrana pupillaris visible;—mouth closed;—fingers completely separated;—inferior extremities of greater length than rudimentary tail;—clitoris and penis very long;—thymus as well as supra-renal capsules present;—cæcum placed below the umbilicus;—cerebrum 5 lines, cerebellum 4 lines, medulla oblongata 1½ line, and medulla spinalis ¾ of a line, in diameter;—two ventricles of heart distinct;—the decidua reflexa and decidua uterina in contact;—funis contains umbilical vessels and a little of the gelatine of Warthon;—placenta completely isolated;—umbilical vesicle, allantois, and omphalo-meseraic vessels have disappeared.

Fœtus of 4 months.—Length 5 to 6 inches;—weight 2½ to 3 oz.;—skin rosy, tolerably dense;—mouth very large and open;—membrana pupillaris very evident;—nails begin to appear;—genital organs and sex distinct;—cæcum placed near the right kidney;—gall-bladder appearing;—meconium in duodenum;—cæcal valve visible;—umbilicus placed near pubis;—ossicula auditoria ossified;—points of ossification in superior part of sacrum;—membrane forming at point of insertion of placenta on uterus;—complete contact of chorion with amnion.

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[*] "Médecine Légale," 3ième edit. tom. i. p. 279.

[†] See, on this last point, Moreau in "Lancette Française," 1837; and Dr. A. Taylor in "Guy's Hospital Reports," 1842.

Fœtus of 5 *months.*—Length 6 to 7 inches;—weight 5 to 7 oz.;—volume of head still comparatively great;—nails very distinct;—hair beginning to appear;—skin without sebaceous covering;—white substance in cerebellum;—heart and kidneys very voluminous;—cæcum situated at inferior part of right kidney;—gall-bladder distinct;—germs of permanent teeth appear;—points of ossification in pubis and calcaneum;—meconium has a yellowish-green tint, and occupies commencement of large intestine.

Fœtus of 6 *months.*—Length 9 to 10 inches;—weight 1 lb.;—skin presents some appearance of fibrous structure;—eyelids still agglutinated, and membrana pupillaris remains;—sacculi begin to appear in colon;—funis inserted a little above pubis;—face of a purplish red;—hair white or silvery;—sebaceous covering begins to present itself;—meconium in large intestine;—liver dark-red;—gall-bladder contains serous fluid destitute of bitterness;—testes near kidneys;—points of ossification in four divisions of sternum;—middle point at lower end of sternum.

Fœtus of 7 *months.*—Length 13 to 15 inches;—weight 3 to 4 lbs.;—skin of rosy hue, thick, and fibrous;—sebaceous covering begins to appear;—nails do not yet reach extremities of fingers;—eyelids no longer adherent;—membrana pupillaris disappearing;—a point of ossification in the astragalus;—meconium occupies nearly the whole of large intestine;—valvulæ conniventes begin to appear;—cæcum placed in right iliac fossa;—left lobe of liver almost as large as right;—gall-bladder contains bile;—brain possesses more consistency;—testicles more distant from kidneys;—middle point at a little below end of sternum.

Fœtus of 8 *months.*—Length 14 to 16 inches;—weight 4 or 5 lbs.;—skin covered with well-marked sebaceous envelope;—nails reach extremities of fingers;—membrana pupillaris becomes invisible during this month;—a point of ossification in last vertebra of sacrum;—cartilage of inferior extremity of femur presents no centre of ossification;—brain has some indications of convolutions;—testicles descend into internal ring;—middle point nearer the umbilicus than the sternum.

Fœtus of 9 *months, the full term.*—Length from 17 to 21 inches;—weight from 5 to 9 lbs., the average probably about 6½ lbs.;—head covered with hair in greater or less quantity, of from 9 to 12 lines in length;—skin covered with sebaceous matter, especially at bends of joints;—membrana pupillaris no longer exists; external auditory meatus still cartilaginous;—four portions of occipital bone remain distinct;—os hyoides not yet ossified;—point of ossification in the centre of cartilage at lower extremity of femur;—white and grey substances of brain become distinct;—liver descends to umbilicus;—testes have passed inguinal ring, and are frequently found in the scrotum;—meconium at termination of large intestine;—middle point of body at umbilicus, or a little below it.

858. From the time of its entrance into the world, the condition of the Human Infant is essentially changed. It is no longer supplied with nutriment by the direct transmission of organizable materials from the circulating fluid of the mother to its own; but obtains it by the processes of digestion, absorption, and assimilation, which involve the establishment of new modes of vital activity in its own organism. In order, however, that the change may not be too sudden, the nutriment provided by Nature for the early period of infantile life, is such as to occasion the least possible demand upon its vital powers, for the preparation of the organizable material which is required for its further growth and development. But the transition is a most important one in another particular; the infant is now thrown in a great degree upon its own resources for the generation of its Heat; and this it is enabled to accomplish by the combustion of a portion of its food which is specially provided for the purpose, this combustion being promoted by the arrangements for that active Respiration, which now supersedes the very limited aeration of its

circulating fluids that was sufficient during fœtal life. In the movements of the respiratory muscles and of the walls of the alimentary canal, we have a new source of expenditure of vital force, and of destruction of tissue; and this expenditure is progressively augmented, as the motions of the body and limbs become increasingly active. Thus we find that the formative powers are not exercised during Infancy and Childhood, solely in the *construction* and *augmentation* of the fabric (as they were during embryonic life), since there is a constant demand upon them for its *maintenance:* and this demand becomes greater and greater, in proportion to the activity of the Animal powers. These, at first called into exercise by the stimulus of sensory impressions upon the Nervous system, are speedily brought into very energetic operation. This operation is of an extremely limited character, being at first purely *sensorial*, and for some time afterwards simply *perceptive.* But the *whole Mind* (such as it is) being given-up to it, *habits of observation* are formed, which are never subsequently lost; the infant learns *how to use* his Organs of Sense; and he also acquires those powers of *interpreting* their indications, which become so completely engrafted into his nature, as henceforth to seem a part of it. Although this Education of the Senses will necessarily go-on, even without any intentional assistance on the part of others, yet it is in the power of the Mother or Nurse to promote it effectually, by supplying objects of various kinds which the Infant may look-at and grasp, and by not abruptly interfering (by the too-speedy withdrawal of such objects) with the process by which the visual and tactile perceptions are blended and harmonized (§ 609).—The Nervous system of the Infant, although thus called into extraordinarily-energetic activity, cannot long sustain that activity; a very large measure of Sleep is required for the restoration of its speedily-exhausted powers; and any unusual excitement of them tends to injurious disturbances of its nutrition. It is owing to this peculiar susceptibility of the Nervous system of the Infant to external influences, that medicines (especially narcotics) which exert a special influence upon that system, are so peculiarly potent in their effects at this period of life, that the greatest caution is needed in their administration.

859. The most important developmental change which occurs in Infancy, after the complete establishment of the extra-uterine circulation (§ 775), is the completion and eruption of the first set of Teeth; the greater part of whose formation, however, has taken-place before birth. These 'milk' or 'deciduous' teeth, 20 in number, usually make their appearance in the following order:—The four central Incisors first present themselves, usually about the 7th month after birth, but frequently much earlier or later; those of the lower jaw appear first. The lateral Incisors next show themselves, those of the lower jaw coming-through before those of the upper; they usually make their appearance between the 7th and 10th months. After a short interval, the anterior Molars present themselves, generally soon after the termination of the 12th month; and these are followed by the Canines, which usually protrude themselves between the 14th and 20th months. The posterior Molars are the last, and the most uncertain in regard to their time of appearance; this varying from the 18th to the 36th month. In regard to all except the front teeth, there is no settled rule as to the priority of appearance of those in the upper or

under jaw; sometimes one precedes, and sometimes the other; but in general it may be stated that whenever one makes its appearance, the other cannot be far off. The same holds-good in regard to the two sides, in which development does not always proceed exactly *pari passu.*—The period of Dentition is sometimes one of considerable risk to the Infant's life; and this especially when an irritable state of the nervous system has been brought-about by unsuitable food, unwholesome air, or some other cause of disordered health. In such cases, the pressure upon the nerves of the gum, which necessarily precedes the opening of the sac and the eruption of the tooth, is a fruitful source of irritation; producing disturbance of the whole system, and giving origin to Convulsive affections which are not unfrequently fatal. These have been particularly studied by Dr. M. Hall, who recommends the free use of the gum-lancet, as a most important means of prevention and cure; but the Author has no doubt that too much attention has been given to the immediate source of the irritation, and too little to the general state of the system; and that constitutional treatment, especially change of air, and improvement of the diet, is of fundamental importance. In infants whose general health is good, and who are not over-fed, Dentition is usually a source of but very trifling disturbance; a slight febrile action, lasting only for a day or two, being all that marks the passage of the tooth through the capsule; and its eruption through the gum taking-place without the least indication of suffering or disorder. Any existing malady or abnormal tendency, however, is pretty sure to be aggravated during the 'cutting of the teeth;' and it is therefore of the greatest consequence, that the infant should be withdrawn during this period from all injurious influences; and that no irregularity of diet, or deficiency of fresh air and exercise, should operate to its disadvantage.

860. Although there are no well-marked divisions between the periods of Childhood, Youth, and Adolescence, through all of which we witness the continuance of the processes of Growth and Development (though in a gradually-decreasing ratio), yet we may appropriately distinguish each as the epoch of one of those important changes which tend towards the completion of the fabric; namely, *Childhood* as ranging through the greater part of the period of the second Dentition,—*Youth* as characterized by that increased evolution of the sexual organs, and by those general constitutional changes accompanying that evolution, which altogether constitute Puberty,—and *Adolescence* as distinguished by that entire consolidation of the Osseous skeleton, which is not completed until the full stature has been attained. It will be convenient first to consider what is common to all these periods; and then to notice the features by which they are severally characterized.

861. The passage from Infancy to Childhood may be regarded as marked by the eruption of the 'deciduous' Teeth; by the termination of that direct supply of food to the offspring, which is afforded until then by the Mammary secretion of the mother; by the dawn of the Intellectual powers, manifested in the first efforts at speaking; and by the acquirement of sufficient control over the muscular apparatus, to render it subservient to the increasing desire which then displays itself for independent Locomotion. All these advances usually take place simultaneously, or nearly so, during some part of the second year; some Infants being much more

forward than others, both in 'cutting their teeth' and in learning to walk and to talk. When they have been completed, the Child enters upon a life which is in many respects new. The alteration of its diet involves a much higher activity of all the organs which are concerned in making blood; whilst its greatly-increased amount of exertion, both of body and mind, gives occasion to a more rapid disintegration of the nervous and muscular tissues, and hence to a higher activity of the Excretory organs. This will, of course, progressively augment, in proportion as the Nervo-muscular apparatus is brought, with advancing years, into more vigorous and more prolonged exercise; until, with the attainment of adult age, the disintegration of these tissues comes to be the chief source of the Excrementitious products. But during the whole period of increase, there is another source of demand for nutritive activity, in that perpetual *re-construction* of the fabric (involving a sort of continual pulling-down and rebuilding on a larger scale, all the old materials being carried-away as useless) which is a necessary condition of its growth: but this demand of course slackens with the diminution of the rate of increase; and at last it ceases altogether, just when the other attains its maximum. Hence the demand for food, on the one hand, and the amount of excretory matter set-free from the body, on the other, are remarkably large during the whole of this period: the child, as every one knows, consuming far more nutriment than the adult, in proportion to the weight of their respective bodies; and the like being true of the quantity of carbonic acid exhaled from the lungs (§ 288, III.), and of the urea given-off from the kidneys (§ 392).—That the germinal capacity, though inferior to that of the embryo, still persists in a high degree during the period of childhood and youth, is shown in the readiness with which the effects of injuries and disease are recovered-from; for although the regeneration of lost parts does not take-place to nearly the same extent as during early embryonic life, yet up to a certain point it is effected with great completeness, and with much greater rapidity than at later epochs. It is still, in fact, rather in the exercise of formative power, than in the production of nervo-muscular vigour, that the vital force of the earlier part of this period is displayed; and we may readily trace such a relation of reciprocity between these two modes of its manifestation, as is strongly indicative of the community of their source. For it is familiar to every observer, that, when the growth of a child or a young person is peculiarly quick, his nervo-muscular energy is usually feeble, and his power of endurance brief, in comparison with that which can be put-forth by one whose frame is undergoing less rapid increase. And we observe, moreover, that the capacity of resistance to depressing influences of various kinds, which is a no less decided manifestation of the vital power of the organism (seeing that these influences are of such a kind as to *tend towards* its death), is possessed by the latter in a far higher degree than by the former. This is remarkably the case in regard to privation of food and depression of external temperature; under which, too, children and young persons succumb much more speedily than adults.

862. It is most interesting to trace, during the progress of the development of the bodily fabric, the gradual expansion and invigoration of the Mental powers. The acquirement of Language constitutes the most

important step in the development of the *ideational* consciousness; and it is easy to recognize in the psychical manifestations of Children, the further progress of that development. The formation of ***Associations*** between ideas takes-place with extraordinary readiness and tenacity during the earliest period of childhood; and these exercise so much influence over the succession of the thoughts during the whole remainder of life, that "the force of early associations" has become proverbial. Out of these associations arise, on the one hand, Memory and Imagination; on the other hand, those simple processes of Reasoning which are necessary to the development of a higher class of ideas. Thus the mind passes from those primary notions of individual objects which are directly suggested by sense-perceptions, to those *abstract* ideas of their qualities, which enable them to recognize those qualities elsewhere, notwithstanding the existence of differences in other respects; and thence to those *general* ideas, in which the abstractions are embodied. In all these processes, the child-mind seems to be so entirely concentrated upon the particular subject of its thoughts, as to be 'possessed' by it for the time, almost as completely as a 'biologized' subject is by his dominant idea; and no prolonged study of it is required to justify the statement, that its operations are for some time entirely *automatic*, and that the acquirement of Volitional control over them, on the part of the individual, is a very gradual process. As a general rule it may be laid-down that the activity with which the formation of new ideas takes-place in the child, and the rapidity with which the attention transfers itself from one object to another, prevents any single state from fixing itself durably in the consciousness, so that the Memory preserves but faint traces of the greater part of what passes through the mind; and it is (for the most part) only when the same thoughts are frequently recurred-to, that they take root (so to speak) in the psychical nature. Still we occasionally find that particular impressions exert a very powerful influence on the subsequent course of thought and feeling; and there is good reason to believe that even where the *consciousness* loses its hold over them, impressions of a transient nature may leave such traces in the Brain, that they may be reproduced at any future time when the appropriate suggestion may happen to be supplied. —Whilst the ideational consciousness is thus being expanded and elevated, the *Emotional* part of the Psychical nature is rapidly acquiring a greater range and intensity of action. The infant and young child give ample evidence in their actions, of the several forms of Emotional Sensibility which connect themselves with Sensational and Perceptive states; but no sooner does the development of Ideas commence, than the various modifications of 'feeling' attach themselves to *these;* and thus almost every thought that is not a purely-intellectual abstraction, comes to possess more or less of an Emotional character. Here, again, we trace the powerful influence of early impressions; for notwithstanding that the state of feeling which is habitual to each individual may depend in great degree upon his original constitution, yet it is unquestionable that it is largely influenced (especially in its association with particular classes of ideas) by *sympathy* with the like states in those among whom the child receives its early education. It is of peculiar importance, therefore, that this example should be such as it is wholesome for the child to imitate;

since it is upon the habits of feeling thus early formed, that the happiness and right conduct of after-life mainly depend. This statement (which applies with yet greater force to the Moral Sense) may at first seem inconsistent with the well-known fact that the Emotions of children are peculiarly transient in their character, even when they are violently excited; one state of feeling giving-place to another, even of the most opposite kind, under the influence of some new impression or of some change in the direction of the ideas. But the same general principle applies to this case, as to the formation of habits of thought; namely, that although individual impressions are more speedily dissipated from the minds of children than from those of adults, yet that when impressions of the same kind are frequently repeated, the brain *grows-to* them in such a manner that they come to take-part (as it were) in its ordinary working; and thus, by establishing a particular mode of nutritive assimilation, they tend to *perpetuate* this acquired habit, of whatever nature it be.—The right training of the Emotional tendencies, and all the higher uses of the Intellectual Faculties, depend in great degree, as may readily be shown, upon the influence of the Will in directing the current of thought and feeling; and this becomes greater and greater, if rightly cultivated, with the advance of years, so that the psychical powers, whilst themselves acquiring an increase of vigour and comprehensiveness, are brought more and more under the control of the individual, and can be utilized in any way in which he may choose to employ them. Thus with a diminishing *mobility* of thought and *excitability* of feeling, the Mind becomes more and more capable of *sustained* and *determinately-concentrated* activity; and is at the same time progressively acquiring that store of familiar *experiences*, which not only constitutes the basis of all attainments in special departments of knowledge, but supplies (when judiciously used) that 'commonsense' by which we form most of our judgments and direct most of our conduct.—During this period, moreover, the Muscular apparatus of Animal life, whose actions are at first purely automatic, is brought more and more under the direction of the Mind, so as to express its ideas, its feelings, and its volitions. And it is whilst this transference is going-on, that new habits of action are most readily formed, and when once formed, are durably impressed upon the organism (§§ 498, 533, 668).—The excess which must exist, during the whole of this period, in the *constructive* over the *destructive* activity, and the large amount of the latter which (as already shown) arises out of the very nature of Growth, in addition to that which proceeds from the increased activity of the Animal functions, necessitates a much larger proportion of repose than suffices for the adult; but this necessity diminishes with the progress of years, for the reasons already mentioned; and thus we find that whilst the young child passes 16 or 18 hours a day in sleep, half that time suffices for the youth just entering on manhood.

863. The *Second Dentition*, consisting in the replacement of the *deciduous* or 'milk' Teeth by the *permanent* Teeth that succeed them, which is the most important developmental change that occurs during the period of Childhood, normally commences in the 7th or 8th year: the germs of the new teeth, however, are formed long previously, having their origin in a process of gemmation from the tooth-sacs of the temporary teeth, which takes-place at a very early period in the development

of the latter. The three permanent Molars on either side of each jaw, however, have no such origin: since they do not replace temporary teeth. The first pair, which usually make their appearance behind the temporary molars, either contemporaneously-with, or a little anteriorly-to, the first shedding of the deciduous teeth, are really 'milk' teeth, so far as their origin is concerned, since they are developed from primitive tooth-sacs: on the other hand, the second true molars, which afterwards come-up behind them, are evolved from tooth-sacs which hold the same relation to those of the first, as the tooth-sacs of the other permanent teeth do to those of the deciduous teeth which they replace; and the third true molars, or *dentes sapientiæ*, bear the like relation to the second. Although the eruption of the true molars is so long postponed, yet the foundation of them is laid at an earlier period; for the papilla of the *first* is distinguishable at the 16th week after conception, that of the second at the 7th month after birth, and that of the third at the 6th year. In the successive replacement of the 'milk' teeth by the 'permanent' set, a very regular order is usually followed. The middle Incisors are first shed and renewed, and then the lateral Incisors. The anterior 'milk' Molars next follow; and these are replaced by the anterior Bicuspid teeth. About a year afterwards, the posterior 'milk' Molars are shed, and are replaced in like manner by Bicuspid teeth. The Canines are the last of the 'milk' teeth to be exchanged; in the succeding year, the second pair of the true Molars appear; but the third pair, or *dentes sapientiæ*, are seldom developed until three or four years subsequently, and often much later.

864. It has been proposed* (and from the evidence adduced in its favour, the proposition would seem entitled to considerable attention) to adopt the successive stages in the Second Dentition, as standards for estimating the physical capabilities of Children, especially in regard to those two periods which the Factory-Laws render it of the greatest importance to determine: namely, the ages of *nine* and *thirteen* years. Previously to the former, a Child is not permitted to work at all; and up to the latter, it may be only employed during nine hours a day. The necessities or the cupidity of Parents are continually inducing them to misrepresent the ages of their children; and it has been found desirable, therefore, to seek for some test, by which the capability of the Child may be determined, without a knowledge of its age. A standard of Height has been adopted by the Legislature for this purpose; but upon grounds which, physiologically considered, are very erroneous; since, as is well known, the tallest children are frequently the weakliest (§ 861). According to Mr. Saunders, the degree of advance of the Second Dentition may be regarded as a much more correct standard of the degree of general development of the organic frame and of its physical powers; and it appears from his inquiries, that it may be relied-on as a guide to the real age in a large proportion of cases; whilst no serious or injurious mistake can ever arise from its use. It may happen that local or constitutional causes may have slightly retarded the development of the Teeth; in which case the age of the individual would rather be under-estimated, and no harm could ensue: on the other hand, instances of premature development of the Teeth very rarely, if ever, occur; so that there is little danger of

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* "The Teeth a Test of Age, considered with reference to the Factory Children." By Edwin Saunders.

imputing to a Child a capability for exertion which he does not possess, as the test of height is continually doing. Moreover, if such an advance in Dentition should occur, it might probably be regarded as indicative of a corresponding advance in the development of the whole organism; so that the real capability would be such as the teeth represent it.—The following is Mr. Saunders's statement of the Ages at which the 'permanent' Teeth respectively appear:—The first true Molars usually present themselves towards the end of the 7th year. Occasionally one of them protrudes from the gum at 6, or more frequently at 6½ years of age; but the evolution of the whole of them may be regarded as an almost infallible sign of the Child being 7 years old. In other instances, where the tooth on one side of the mouth is freely developed, it is fair to reckon the two as having emerged from their capsules; since the development of the other must be considered as retarded. This rule only holds good, however, in regard to teeth in the same row; for the development of the teeth in either jaw must not be inferred from that of the corresponding teeth in the other. With this understanding, the following table will probably be very near the truth:—

Central Incisors developed at	8 years.
Lateral Incisors	9 ,,
First Bicuspid	10 ,,
Second Bicuspid	11 ,,
Canines	12 to 12½
Second Molars	12½ to 14

The following are the results of the application of this test, in a large number of cases examined by Mr. Saunders. Of 708 children of *nine* years old, 530 would have been pronounced by it to be near the completion of their *ninth* year; having the central, and either three or four lateral, incisors fully developed. Out of the remaining 178, it would have indicated that 126 were 8½ years old, as they presented one or two of the lateral Incisors; and the 52 others would have been pronounced 8 years old, all having three or four of the central Incisors. So that the extreme deviation is only 12 months; and this in the inconsiderable proportion (when compared with the results obtained by other means) of 52 in 708, or 7⅓ per cent. Again, out of 338 children of 13 years of age, 294 might have been pronounced with confidence to be of that age; having the Canines, Bicuspid, and second Molars, either entirely developed, or with only the deficiency of one or two of either class. Of the 44 others, 36 would have been considered as in their 13th year, having one of the posterior Molars developed; and 8 as near the completion of the 12th, having two of the Canines, and one or two of the second Bicuspid. In all these instances the error is on the favourable side,—that is, on the side on which it is calculated to prevent injury to the objects of the inquiry; in no instance did this test cause a Child to be estimated as older or more fit for labour than it really was.*

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* The value of this test, as compared with that of Height, is manifested by a striking example adduced by Mr. Saunders. The height of one lad, J. J., aged 8 years and 4 months, was 4 feet and ¾ of an inch; that of another boy, aged 8 years and 7 months, was only 3 feet 7¼ inches. According to the standard of height adopted by the Factory

865. The period of *Youth* is distinguished by that advance in the evolution of the Generative apparatus in both sexes, and by that acquirement of its power of functional activity, which constitutes the state of *Puberty*. Of the principal changes in which this consists, in the two sexes respectively, an account has already been given (§§ 723, 730, 799); and it is merely requisite here to add, that this augmented development can only be rightly regarded as *preparatory* to the exercise of these organs, and not as showing that the aptitude for their exercise has already been fully attained. It is only when the growth and development of the *individual* are completed, that the procreative power can be properly exerted for the continuance of the *race;* and all experience shows that by prematurely and unrestrainedly yielding to the sexual instincts, not merely the generative power is early exhausted, but the vital powers of the organism generally are reduced and permanently enfeebled; so that any latent predisposition to disease is extremely liable to manifest itself; or the bodily vigour, if for a time retained with little deterioration, early undergoes a marked diminution.

866. After the attainment of Puberty, no marked alteration takes-place in the organism, save the continuance of its increase in stature, usually for a few years longer (§ 797); which increase is the chief manifestation of the excess of the germinal capacity, that has not yet expended itself in the building-up of the fabric. But so long as this increase is going-on, there is a want of that solidity and compactness of the organism which seem only attainable when growth has ceased; and the attainment of which, being essential to the highest manifestations of vigour and endurance, marks the final completion of its development. Of this we have the best illustration in the *Osseous* system; whose completion, being postponed until all further *growth* has ceased, may be fairly considered as marking the final stage in the development of the organism, and as therefore characterizing the period of *Adolescence*.—Commencing with the *Vertebral Column*, we find that whilst the 'body' and 'neural arches' of each vertebra become consolidated in early childhood, the spinous and transverse processes are completed by separate 'epiphyses,' the ossification of which does not commence until after puberty, and the final union of which with the body of the bone may not occur until the age of twenty-five or thirty years. About the same time, there is formed and added to each surface of the body of the vertebra a smooth annular plate of solid bone, which covers a portion that was previously rough and fissured. During this period, the consolidation of the Sacrum is proceeding; the component vertebræ of which remain separate up to about the sixteenth year, and then begin to unite from below upwards, the union of the two

Commissioners (namely 3 feet 10 inches), the *taller* lad would have been judged fit for labour, whilst the *shorter* would have been rejected. The Dentition of the latter, however, was further advanced than that of the former; for he had two of the lateral Incisors, whilst the former had only the central: and the determination of their relative physical powers, which would have been thus formed, would have been in complete accordance with the truth. The elder boy, though shorter than the other by 5¼ inches, possessed a much greater degree both of corporeal and mental energy, and his pulse was strong and regular; whilst that of the younger lad, who was evidently growing too fast, was small and frequent.—An instance even more striking has come under the Author's own observation.

highest being completed by about the twenty-fifth or the thirtieth year; whilst at the same time thin osseous plates are formed on either side of the coalesced mass, which seem to represent the epiphyses of the transverse processes of its component vertebræ, and like them are finally joined-on to the body of the bone. The ossification and coalescence of the Coccygeal vertebræ takes-place at a still later period. Each Rib in like manner has two epiphyses, one for the head and the other for the tubercle; the ossification of which begins soon after puberty, whilst their union with the body of the bone is not completed until some years afterwards. The five pieces of which the Sternum consists, though themselves completely ossified, remain separate until after the age of puberty; when their union commences from below upwards, as in the sacrum, not being always completed, however, even in old age, by the junction of the first piece to the rest of the bone. The ossification of the Ensiform cartilage does not commonly begin until after the age of puberty; and it is usually not entirely completed even in very advanced life.—The ossific union of the separate elements of the *Bones of the Skull* (§§ 786, 787), is usually completed within a few years after birth; but there are some parts which not unfrequently remain distinct during the greater portion of life, and which may even never coalesce; such is the case with the two halves of the Frontal bone, which often remain permanently divided by a continuation of the sagittal suture, and with the Styloid process of the temporal bone. In the *Upper extremities*, we find the Scapula presenting three epiphyses, one for the coracoid process, one for the acromion, and one for the lower angle of the bone; the ossification of which begins soon after puberty, their union with the body of the bone taking-place between the ages of twenty-two and twenty-five years. The Clavicle has an epiphysis at its sternal end, which begins to form between the eighteenth and twentieth years, and is united to the rest of the bone a few years later. The consolidation of the Humerus is completed rather earlier; the large piece at the upper end, which is formed by the coalescence of the ossific centres of the head and two tuberosities, unites with the shaft at about the twentieth year; whilst its lower extremity is completed by the junction of the external condyle and of the two parts of the articulating surface (previously united with each other), at about the seventeenth year, and by that of the internal condyle in the year following. The superior epiphyses of the Radius and Ulna unite with their respective shafts at about the age of puberty; the inferior, which are of larger size, at about the twentieth year. The epiphyses of the Metacarpal and Phalangeal bones are united to their principals at about the twentieth year.—In the *Lower extremities*, the process of ossification is completed at nearly the same periods as that of the corresponding parts of the upper. The consolidation of the Ilium, Ischium, and Pubis, to form the Os Innominatum, by the ossification of the triradiate cartilage that intervenes between them in the acetabulum, does not take-place until after the period of puberty; and at this time additional epiphyses begin to make their appearance on the crest of the ilium, on its anterior inferior-spine, on the tuberosity of the ischium, and on the inner margin of the pubes, which are not finally joined to the bone until about the twenty-fifth year.

867. The rapid increase in *Viability* which shows itself in both sexes up to the age of puberty, its rapid decline from that point, and its sub-

sequent increase in the male up to the age of thirty, have been already pointed-out (§ 797). The disorders to which the organism is most subject during the several periods which have now been considered, are by no means the same for each. In early Childhood, when there is a great demand for the activity of the Digestive and Assimilative functions, and these have to be exercised upon nutriment to which their organs are not yet accustomed, we find derangements of those organs to be among the most common of all maladies; these may be serious enough in themselves to constitute dangerous and even rapidly-fatal diseases; but even when they do not take these acute forms, a foundation is often laid, in habits of perverted Nutrition thence arising, for disorders of a more chronic nature (especially those depending on the Tubercular diathesis, § 360), which may not manifest themselves for many years afterwards. The peculiar activity of the nervous centres, which is prolonged from Infancy into early Childhood, involves a continued liability to derangements of *their* nutrition or of their functions; and thus it happens that in young children of scrofulous temperament, it is either in the mesenteric glands, or in the brain or its membranes, that tubercular deposit first takes place. The second Dentition, like the first, is often accompanied with a great deal of constitutional disturbance; especially in such individuals as are suffering from defective Nutrition, or from an irritable state of the Nervous System. In the former case, there is a special proneness to Tubercular disease;* in the latter, to Epilepsy, Chorea, or some other form of disorder of the nervous centres, the connection of which with Dentition is shown by its abatement when that epoch has passed. A large part of the sickness and mortality, however, which presents so high a rate during the whole period of Childhood, is due to various forms of Zymotic disease, especially the Exanthemata and Infantile Remittent Fever, and to their *sequelæ*.†—The attainment of Puberty in the Male sex is not usually attended with any specific tendency to disease; nor would it probably be in the Female, if her mode of life were more accordant with the rules of health. Although disorder of the Menstrual function is one of the most common phenomena of female youth, yet it is undoubtedly to be looked upon more frequently as a symptom of general defect of nutrition (and especially of an impoverished condition of the blood), than as itself constituting a disease. The extraordinary reduction in the probability of life, indicating a large mortality, during the years which immediately succeed puberty, seems to depend in great degree, in the Male, upon the premature use of his generative powers, and upon his entrance upon the active employments of life before his constitution has received that invigoration which results from the completion of his bodily development; whilst in the Female it is very commonly attributable to the accumulation of unhealthy influences, which begin to 'tell' upon the powers of her system, when its germinal capacity no longer ministers to its active regeneration. It is *then*, in both sexes, though from causes whose immediate nature is different, that the Tubercular diathesis is prone to develope itself with peculiar intensity, and that, by fixing upon the Respiratory organs, it produces the most rapidly-fatal alterations in structures whose integrity is essential to life.

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* It is a very significant circumstance, that of the many specimens of the Anthropoid Apes which have been brought alive to this country, not one has survived its second dentition; and that, in almost every case, it has been by tubercular disease that their lives have been thus prematurely cut-off.

† The effects of affluence and poverty on the duration of life at this period are remarkably shown by the deductions of Casper of Berlin, who states as the result of his inquiries that of 1000 children born in the families of affluent persons, 911 attained the age of 15 years; whilst of 1000 paupers, only 584 survived to that age. (Béclard, "Physiologie," 1862, p. 594.)

868. *Period of Maturity.*—The cessation of growth, and the completion of the developmental processes, which indicate the attainment of *Manhood*, are accompanied by a marked increase in the general vigour of the organism, and by a special augmentation in the power of *endurance* in the exercise of the Animal faculties. With the exception of those parts of the fabric whose utility was confined to the earlier periods of its development, we find every organ now presenting its greatest capacity for sustained activity; and thus it is from the characters which each presents at this period, that we base our ideas of its *typical* perfection of structure and composition. All the previous changes which the organism has undergone, both as a whole and in its separate parts, concur to the attainment of this perfection, as we have especially seen in regard to the evolution of the solid framework of the body; and every subsequent change, as we shall presently perceive (§ 870), involves a deterioration from it. The whole *nisus* of development, during this period, appears to be directed towards the *maintenance* of the organism in the state which it had acquired at its commencement; by the regeneration of its tissues as fast as they undergo disintegration, and by the renovation of its vital force in proportion as this is expended. There is no longer any capacity for the production of new organs, and comparatively little for the augmentation of those already existing; the increase of the Uterine and Mammary structures, during the period of gestation, being the most important examples of formative power, and these presenting themselves in the sex in which there is least of nervo-muscular activity and of general vigour. We should infer then, that the 'germinal capacity' is now on the decline; and this further appears from the diminished energy and completeness with which the reparative processes are performed, as compared with the mode in which they are executed during the period of growth. There is consequently a less demand for alimentary material (allowance being made for the augmented bulk of the body) than during the previous periods; and the dependence of life upon a constant supply of aliment is far less close. Moreover, the ordinary rate of waste or degeneration of tissue is now much less rapid than during the period of growth; for we have seen that decay and removal, in the latter case, are among the very conditions of increase; whilst in the former, they proceed, for the most part, only from the expenditure of the vital powers of the tissues, consequent upon their functional activity. Hence it is upon the degree in which the *Animal* powers are exercised, that the demand for food chiefly depends in the Adult; the sole purpose of the Organic or Vegetative operations being (so to speak) to keep the apparatus of Animal life, now fully developed, in working-order. The relative activity of the different parts of this apparatus is now somewhat modified. The *observing faculties* no longer possess the same pre-eminence; the *emotional sensibility* is less readily excited; but the *intellectual powers* now act, in the modes which have become habitual to them, with a sustained vigour and completeness

which they never previously possessed. And so, whilst the muscles are not so easily excited to contraction, and new combinations of movement are acquired with far more difficulty than during the period of growth and development, the force which they can generate by their contraction is augmented, and this force can be kept-up for a much longer time in adults than in younger subjects.

869. The duration of the period over which this 'maintenance' may be protracted, without any sensible deterioration, depends in great degree upon the due observance of all the conditions of health. If the various mental and bodily faculties are duly exercised, without being overtasked,—if an amount of sleep adequate to their periodic renovation be regularly taken,—if a sufficient but not excessive quantity of wholesome food be ingested at appropriate intervals,—if the functions by which the blood is prepared, and those by which it is kept in purity, be duly performed,—if all such noxious agents as foul air, strong alcoholic liquors, tobacco-smoke, be kept at a distance,—and there be no constitutional predisposition to disease on the one hand, nor any exposure to extraneous morbific causes on the other,—it may be fairly anticipated that the bodily and mental vigour may be sustained with little deterioration during a long succession of years. The circumstances that most tend to premature decline, are, on the one hand, excessive exertion either of the mental faculties or of the generative power; or, on the other, undue indulgence in food, or in stimulating drinks, or in any practice that tends to disorder the Organic functions, especially by exciting them to undue activity. Every one who, in *any* of these modes, may " live too fast," is almost certain to pay the penalty in an abbreviation of his term of vigorous activity; which may be either brought to a sudden and final close by fatal disease, or may be prematurely reduced by more gradual decay. And this tendency will of course be more decided, the greater is the amount, and the larger the combination, of those departures from the Laws of Health which give rise to it.

870. *Period of Decline.*—The *decline of life* exhibits a much more obvious diminution of the whole vital power of the organism; for not only is its formative activity now greatly reduced, but its nervo-muscular energy and general vigour progressively diminish, and its generative power becomes enfeebled, or ceases entirely (§§ 723, 732). Of this diminution in formative power we have evidence in the entire absence of any attempt at new development, in the less perfect and more tedious manner in which the losses of substance occasioned by disease or injury are recovered-from, and in the gradual deterioration of the organism in general. The tissues which are rendered effete by their functional activity, are not any longer replaced in their normal completeness; for either the quantity of new tissue is inadequate, so that the bulk of the organs is obviously reduced; or their quality is rendered imperfect by the production of structures in various phases of degeneration, in place of those which had been previously developed in the fullest completeness. The inferiority of Nervo-muscular energy and of general vigour are thus evidently the result of the deficiency, and not (as in the period of growth) of the excess, of formative power; and in proportion as the 'waste' of the tissues, consequent upon their functional activity, is more rapid than their renovation, a progressive loss of substance must take-place. The forms of Degeneration most com-

monly met-with in advanced age, are the *fatty* and the *calcareous*. The former (§ 333) is extremely prone to show itself in those organs whose integrity of structure is peculiarly important to health, and whose deterioration interferes directly with the *vital* properties of their component tissues. Thus we observe it in the Muscular apparatus generally, but pre-eminently in the walls of the Heart; and in proportion as its contractile fibre has been replaced by particles of fat, must the vital energy of any muscle be lowered. So, again, we find the same degeneration in the Liver, Kidney, and other parts of the Glandular apparatus; the proper secreting action of which is impaired in the ratio of the substitution of fat for the proper Glandular elements. But it may also lead to most serious derangements of the vital functions, by its interference with the purely-mechanical actions of certain parts of the organism; thus, fatty degeneration of the walls of the Blood-vessels is one of the most frequent causes of those extravasations of blood in the nervous centres, which give rise to the apoplexy and to the various forms of paralysis so common among the aged; and the same change occurring in the Bones, gives them that peculiar brittleness which they frequently exhibit in advanced periods of life. That general decline of the vital powers, which has received the name of 'climacteric disease,' appears traceable to the same source.*—The tendency of the calcareous degeneration (which especially affects the Cartilaginous and Fibrous tissues) is almost exclusively to interfere with the *mechanical* adaptations of the organism; producing an injurious rigidity in various structures which require a greater or less amount of flexibility for the normal performance of their functions. Thus it is very common for the cartilages of the ribs to become ossified in advanced life, so as to interfere with the free movement of the walls of the thorax; and the thyroid cartilages of old people are frequently converted into bone, producing a roughness of the voice, and deficiency of the power of modulating it. The intervertebral substance (which is partly cartilaginous and partly fibrous) not unfrequently becomes solidified in the lumbar region, as do also the spinal ligaments, so that several of the lower vertebræ are firmly anchylosed to each other and to the sacrum; and a like change often takes-place in the pelvic articulations, so that the pelvis and the lower part of the spine become one continuous mass of bone, destitute of flexibility or yieldingness in any part. In like manner the cranial sutures often become obliterated, and calcareous deposits occur in the duplicatures of the dura mater forming the falx and tentorium. A large amount of this kind of change may take-place without any serious interference with the Organic functions, although it tends to curtail the Animal powers. When the calcareous degeneration, however, extends itself to the vital organs, the interruption which it occasions in their actions may be fatal; thus, next to fatty degeneration, there is probably no more frequent cause of failure of the heart's action, or of extravasation from the blood-vessels, in old persons, than ossification of the valvular apparatus of the former, depriving it of the flexibility which is essential to its proper action, or of the fibrous walls of the latter, imparting to them a brittleness which predisposes to rupture.†

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* See Mr. Barlow's 'General Observations on Fatty Degeneration,' in the "Medical Times and Gazette," May 15, 1852.

† A good account of these changes will be found in the "Practical Treatise on the Diseases and Infirmities of Advanced Life," by Daniel Maclachlan, M.D.; 1863.

871. Thus, then, with the advance of Old Age, the organism becomes progressively more and more unfit for the active performance of its vital operations; a gradual weakening is observable in the Mental as well as in the Corporeal energy; and a retardation becomes obvious in the current of Organic life. The mind is far less active than in the periods of Maturity; the perceptions are dull, the feelings comparatively obtuse (save where some dominant emotion has gained possession, through the previous habit of yielding to it), the intellectual powers cannot be so readily put in action, and the imagination loses its vividness. There are few instances in which any great works, either literary or artistic, have been executed after the age of threescore. Still, the experience of a long life gives value to the judgment; and the counsels of the old, where the bearings of the question can be fully understood, deserve the respect of the young, more especially in cases where temporary ardour of feeling tends in the latter to supersede the dictates of their calmer reason.—The mental torpor is correlated, there seems no reason to doubt, with changes in the condition of the Nervous substance, which impair its original activity; and like changes, occurring in the Muscular substance, diminish its capacity for physical exertion. Hence there is, on the one hand, a marked diminution in the demand for food; on the other, a like diminution in the rate of the excretory processes, as is seen especially in the exhalation of carbonic acid (§ 288, III.) and in the excretion of Urea (§ 392): and in accordance with all these reductions, there is a greatly diminished power of sustaining the heat of the body, the temperature of which consequently becomes liable to a serious depression from external cold. This retardation of vital activity gradually becomes more and more marked, until, if neither accident nor disease should intervene, the current stops of itself; the formative power seems to undergo a progressive exhaustion, until no assistance from artificial heat, no supply of the most nutritious food, can any longer avail for the generation of new tissue; the nervo-muscular energy gradually declines, until at last even those actions on which the circulation and respiration entirely depend can no longer be performed; and with the cessation of these functions, the Life of the entire organism becomes extinct.—Such we may consider to be the mode in which *Death* normally occurs. Various abnormal influences, however, remain to be considered, which may bring about this final result at an earlier period, and in different modes (Chap. XIX.).

CHAPTER XIX.

OF DEATH.

872. We have seen it to be inherent in the very nature of Vital Action, that it can only be sustained during a *limited period* by any Organized body; for although the duration of certain structures may be prolonged, and their vital properties retained, almost indefinitely, yet this is only when the withdrawal of all extraneous agencies has reduced them to a condition of complete inactivity. The Organized fabric, in fact, is at the same time the *instrument* whereby Vital Force is exercised, and the *subject* of its operation; and of this operation, *decline* is no less a constituent part than *development*, and *Death* is its necessary sequence. Hence, in the performance of each one of those Functions whose aggregate makes-up the Life of Man, the particular organ which ministers to that function undergoes a certain loss by the decline and death of its component tissues; and this the more rapidly in proportion to the activity of the changes which are effected by their instrumentality. But if the regenerative processes be also performed with due vigour, no deterioration of the organ is manifested, since every loss of substance is compensated by the production of an equivalent amount of new and similar tissue. This regenerative power, however, gradually diminishes with the advance of years; and thus it happens that the entire organism progressively deteriorates (§ 870), and that Death at last supervenes from a general failure of the vital powers, rather than from the perversion or cessation of any one class of actions in particular.

873. But Death may occur at any period of Life, from some local interruption produced by disease or injury in the regular sequence of vital actions; such interruption extending itself from the part in which it commences, to the organism in general, in virtue of that intimate mutual dependence of one function upon another, which is characteristic of all the higher orders of living beings. The death of the body as a whole, which may be appropriately designated *Somatic** death, becomes a necessary consequence of the death of a certain part of it, or *Molecular* death, only when the cessation of activity in the latter interferes with the elaboration, the circulation, or the depuration of the Blood, which supplies not merely the nutritive *pabulum* to every part of the organism, but also the oxygen which is essential to the activity of the Nervo-muscular apparatus. Thus, even in the higher animals, the death or removal of the limbs, although they may constitute (as in Man) a large proportion of the fabric, is not necessarily fatal; because it involves no interruption, either in the nutritive operations of the viscera, or in the sensorial functions of the brain.† On the other hand, the destruction of a

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* This term was first suggested by Dr. Prichard, in place of the less accurate term 'systemic' which was previously in use. (See "Cyclop. of Anat. and Physiol.," vol. i. p. 791.)

† The Author has been informed by Dr. Daniell, that it is not at all uncommon, in

certain minute portion of the Nervous centres, or such a lesion of the Heart's structure as would be trivial in almost any other organ, may be the occasion of immediate death; because these changes arrest the Respiratory movements, or interfere directly with the action of the Heart, so as to bring the flow of blood to a stand. It sometimes happens, however, that life may be prolonged after the death or removal of some important organ, in consequence of the power which some other possesses of discharging its function; thus we find that in Man the kidneys seem occasionally to take upon themselves the elimination of the constituents of bile from the blood (§ 367); and in the Frog the skin can perform part of the office of the lungs, so as to effect the aeration of the blood in a sufficient degree to prolong life for some time, unless the temperature be elevated.*

874. But although the vital activity of every part of the body is dependent upon a due supply of circulating fluid, yet this dependence is usually not so close as to involve the *immediate* suspension of vital activity, or *Molecular Death*, in every part, whenever the general Circulation shall have been brought to a stand. For we have distinct evidence of the persistence of vital changes in various organs and tissues of the body, after the death of the body at large; as is manifested in the performance of ciliary and of muscular movements, in acts of secretion and perhaps even of nutrition,† in the maintenance of the local circulation (§ 242), and in the generation of animal heat (§ 406); and the fact is even yet more remarkably manifested in the reunion (even after the lapse of some hours) of parts that have been entirely severed, such as fingers or toes, noses or ears, by adhesion between the cut surfaces when brought into apposition, which could not take place if the severed part were already *dead*.

875. The permanent and complete cessation of the Circulating current, which essentially constitutes *Somatic* Death, may be directly or indirectly consequent upon several distinct causes.—In the *first* place, it may be due to failure in the propulsive power of the Heart, which constitutes *Syncope*. This failure may occur either (*a*) in consequence of a loss of the proper irritability of the Muscular tissue, or (*b*) through the supervention of a 'tonic spasm,' the organ remaining rigidly contracted without its usual alternation of relaxation. The phenomena attending death

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Negroes who are in the last stage of the adynamic fevers of the African coast, for death and decomposition to extend gradually upwards from the extremities to the trunk; so that the former may be in a state of absolute putrescence, before the respiration and circulation have been brought to a stand: and he learns from Prof. Jackson of Philadelphia, that he has more than once witnessed the same occurrence.

* That such cannot take-place in Man, is due not merely to the far less complete adaptation of his skin for the aeration of the blood, but also to the difference in the type of his circulation, which causes the arrest of blood in the pulmonary vessels to produce a stagnation of the entire current.

† Thus Mr. T. Bell mentions ("History of British Reptiles," p. 61), that having been engaged in the careful dissection of the poison-apparatus of a large Rattlesnake, although the animal had been dead for some hours, and the head had been taken-off immediately after death, yet the poison continued to be secreted as the dissection proceeded, so as to require to be occasionally dried-off with a bit of sponge.—A growth of Hair is said to have been noticed in several instances after death; and if the temperature of the surrounding medium be not too low for the vital activity of the hair-bulbs, there seems no adequate reason why this should not take-place.

in the two cases are not dissimilar, when the loss of irritability is sudden and immediate (as when it arises from violent impressions on the nervous system); for the individual suddenly turns-pale, falls-back or drops-down, and expires with one gasp. But under the former condition, the heart is found *flabby*, sometimes empty, sometimes distended with blood, both cavities being equally filled; whilst in the latter the heart is contracted and hard, containing little or no blood, as when in the state of *rigor mortis*. —The cause of the loss of irritability, when sudden, usually lies in the influence of a 'shock' transmitted through the Nervous system, and originating either in some severe lesion of its central organs or of its peripheral expansion (§ 216), or in a deficiency of its supply of blood or diminution of its usual pressure (such as is produced by rapid detraction of blood, especially in the erect posture, by the rapid removal of the fluid in ascites without the substitution of artificial pressure, or by suddenly rising into the erect posture after prolonged recumbency,* still more, after long stooping), or in some powerful mental emotion, either exciting or depressing. A more gradual effect of the same kind is produced by severe lesions of the internal organs (such as rupture of the uterus), which often prove fatal by the general 'collapse' thus induced, rather than by the disturbance which takes-place in their own proper functions; and this seems to be the usual *modus operandi* of corrosive poisons, whose effect upon the heart's action resembles that produced by severe burns of the surface in children. The influence of the proper *sedative* poisons, however,—such as digitalis, tobacco, aconite, and upas,—seems to be directly exerted, through the blood, upon the tissue of the heart itself; and the same is probably the case with some of those 'morbid poisons,' whose introduction into the system gives rise to diseases of the most intensely adynamic type, such as Malignant Cholera, in which the 'collapse' is out of all proportion to any local lesion. But, again, the loss of the Heart's irritability may be a gradual process, resulting from the deterioration of its tissue by fatty degeneration or by simple atrophy; and this last condition may be due to deficiency of blood, as happens in chronic starvation and diseases of exhaustion, in which the failure of the circulation seems due to the weakening of the heart's power and to the lowering of the quantity and quality of the blood, acting as concurrent causes, the condition thus induced being appropriately designated *Asthenia*. In all cases it is to be observed that when the Vital powers have been previously depressed, a much slighter impression on the Nervous system is adequate to produce Syncope, than would be required when it is in a state of full vigour.—The causes of the tonic spasm of the heart have not been clearly made-out; but it seems producible, like the more common form of Syncope, by agencies operating through the Nervous system; thus it has supervened upon the ingestion of a large quantity of cold water into the stomach.

876. Somatic Death may be occasioned, *secondly*, by an obstruction to the flow of blood through the capillaries of the lungs, constituting *Asphyxia* (§ 298); and this may be consequent upon a disordered state

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* Hence it is that great caution should be exercised, in allowing patients who are convalescent from acute diseases to rise into the erect position; many cases of fatal syncope having been thus induced. The state of general debility, and the continued recumbency, both favour this result, especially in persons advanced in life.

of the lungs themselves, or upon suspension of the respiratory movements through affections of the Nervous centres. It is in this mode that most fatal disorders of the Nervous System produce death, except when a sudden and violent impression occasions a cessation of the heart's power; thus in Apoplexy, Narcotic Poisoning, &c., death results from the paralyzed condition of the Medulla Oblongata; whilst in Convulsive diseases, the fatal result generally ensues upon a spasmodic fixation of the respiratory muscles.—*Thirdly*, Somatic death may be occasioned by a disordered condition of the *Blood* itself (§ 182), which at the same time weakens the power of the Heart, impairs the activity of the Nervous system, and prevents the performance of those changes in the systemic Capillaries, which afford a powerful auxiliary to the circulation. This is Death by *Necræmia.**—*Fourthly*, Somatic death may result directly from the agency of *Cold*, which stagnates *all* the vital operations of the system. Where the cooling is due to the agency of an extremely low external temperature, which acts first upon the superficial parts, there is reason to think that the congestion of the internal vessels thereby induced, occasions a torpid condition of the Nervous centres, and that the cessation of the Circulation is immediately due to Asphyxia. But when the cooling is gradual, and the loss of heat is almost equally rapid throughout, it is obvious that the stagnation must be universal, and that no cessation of activity in any one part is the occasion of the torpor in the functions of the remainder. It is in this manner that death ordinarily results from Starvation, and not by the weakening of the heart's action, as commonly supposed; the proofs of this have been already stated (§ 411).

877. As a general rule, we find that the more active the changes which normally take place in any tissue during life, the more speedily does its *Molecular* Death follow Somatic Death, the requisite conditions of its vital action being no longer supplied to it. Thus we observe that in Cold-blooded animals, the supervention of Molecular upon Somatic death is much less speedy than it is in Birds and Mammals. This seems due to two causes. In the first place, the tissues of the former, being at all times possessed of a lower degree of vital activity than those of the latter, are disposed to retain it for a longer time; according to the principle already laid-down. And, secondly, as the maintenance of a high temperature is an essential condition of the vital activity of the tissues of Warm-blooded animals, the rapid cooling of the body after Somatic death is calculated to extinguish it speedily; and that this cause has a real operation, is evinced by the influence of artificial warmth in sustaining the vital properties of separated parts.—The rapidity, however, with which Molecular death follows the cessation of the general circulation, will be influenced by a variety of causes; but especially by the degree in which the condition of the solids and fluids of the body has been impaired by the mode of death. Thus in Necræmia, Asthenia, and death by gradual cooling, Molecular and Somatic Death may be said to be simultaneous; and the same appears to be true of death by sudden and violent impressions on the Nervous system (§ 216). But in many cases of death by causes which operate by producing a more gradual Syncope or Asphyxia, the tissues and blood having been previously in a healthy

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* See Dr. C. J. B. Williams's "Principles of Medicine," 3rd edit., p. 553.

condition, Molecular death may be long postponed; and we cannot be quite certain that it has supervened until signs of actual decomposition present themselves.

878. When Molecular death takes-place in an isolated part, it must result from some condition peculiar to that part, and not primarily affecting the body in general. Thus we may have Gangrene or Mortification of a limb as a direct result of the application of severe cold, or of an agent capable of producing chemical changes in its substance, or of violent contusions occasioning mechanical injury; or, again, from an interruption to the current of nutritive fluid; or, further, from some ill-understood stagnation of the nutritive process, which manifests itself in the spontaneous death of the tissues without any assignable cause, as in some cases of senile gangrene. Sometimes we are enabled to trace this stagnation to a disordered condition of the circulating fluid; as in the gangrene resulting from the continued use of the 'ergot' of rye or wheat; but we can give no other account of the almost invariable commencement of such gangrene in the extremities, than we can of the selection of lead, introduced into the blood, by the extensors of the fore-arm.—If Mortification or Molecular Death be once established in any part, it tends to spread, both to contiguous and to distant portions of the body. Thus we have continually to witness the extension of gangrene of the lower extremities, resulting from severe injury or from the use of the ergot, from the small part first affected, until the whole limb is involved; and this extension is easily accounted-for, by our knowledge of the tendency of organic substances in the act of decomposition, to produce a similar change in other organic substances subjected to the influence of proximity to them. And the propagation of the gangrenous tendency to remoter parts, is obviously due to the perversion of the qualities of the Blood, which results from a similar cause.*

879. It is quite certain that an *apparent* cessation of *all* the vital functions may take-place, without that entire loss of vitality which would leave the organism in the condition of a *dead* body, liable to be speedily disintegrated by the operation of chemical and physical agencies. The state of Syncope is sometimes so complete that neither can the heart's action be perceived nor any respiratory movements be observed, all consciousness and power of movement being at the same time abolished; and yet recovery has spontaneously taken place, which could scarcely have been the case if *all* vital action had been suspended.—It is not a little remarkable, that certain individuals have possessed the power of *voluntarily* inducing this condition. The best-authenticated case of this kind is that of Col. Townsend, which was described by Dr. George Cheyne,† who was himself the witness of the fact. But statements have been recently made respecting the performances of certain Indian Fakeers, which are far more extraordinary; it being demonstrated, if these assertions are to be credited,‡ that the Human organism may not only be

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* On the proximate causes of Death, see especially the Art. 'Death,' by Dr. Symonds, in the "Cyclop. of Anat. and Phys.," vol. i.; the first chapter of Prof. Alison's "Outlines of Pathology and Practice of Medicine," and Dr. C. J. B. Williams's "Principles of Medicine," 3rd edit., pp. 536–557.

† See his "Treatise on Nervous Diseases," p. 307.

‡ See a collection of these cases, directly obtained from British officers who had been

voluntarily reduced to a state resembling profound collapse, in which there appears to be a nearly complete suspension of all its vital operations, but may continue in that condition for some days or even weeks, until, in fact, means are taken to produce resuscitation.—Another form of apparent death, the existence of which appears to be well-authenticated, is that sometimes designated as 'Trance' or 'Catalepsy,' in which there is a reduction of all the Organic Functions to an extremely low ebb, but in which Consciousness is still preserved, whilst the power of voluntary movement is suspended; so that the patient, though fully aware of all that is being said and done around, is unable to make the least visible or audible sign of life.* It is impossible, in the present state of our knowledge, to give any satisfactory account of these states; but some light appears to be thrown upon them by certain phenomena of artificial Somnambulism, 'hypnotic' or 'mesmeric' (§ 576); for in this condition, there is sometimes an extraordinary retardation of the respiratory movements and of the pulsations of the heart, which, if carried further, would produce a state of complete collapse; and its self-induction is suspected by Mr. Braid to be the secret of the performance of the Indian Fakeers just referred-to.

880. The signs by which *real* is certainly distinguishable from *apparent* Death, are not numerous, a large proportion of those commonly relied-on being fallacious; but they are conclusive.—In the first place, it is to be remarked that no reliance is to be placed, for the reasons already mentioned, upon the apparent cessation of the Heart's action and of the Respiratory movements; since the reduction of these to so low a condition that they are no longer distinguishable, is by no means incompatible with the persistence of vitality. A surer test, however, is afforded by the condition of the *Muscular* substance; for this gradually loses its irritability after real Death, so that it can no longer be excited to contraction by electrical or any other kind of stimulation; and the loss of irritability is succeeded by the appearance of cadaveric rigidity. So long, then, as the

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eye-witnesses of them in India, by Mr. Braid, in his "Observations on Trance, or Human Hybernation," 1850.—In one of these, vouched-for by Sir Claude M. Wade (formerly political agent at the Court of Runjeet Singh), the Fakeer was buried in an underground cell, under strict guardianship, for *six weeks;* the body had been twice dug up by Runjeet Singh during the period of interment, and had been found in the same position as when first buried.—In another case, narrated by Lieut. Boileau, in his "Narrative of a Journey in Rajwarra, in 1835," the man had been buried for ten days, in a grave lined with masonry and covered with large slabs of stone, and strictly guarded; and he assured Lieut. B. that he was ready to submit to an interment of a twelvemonth's duration, if desired.—In a third case, narrated by Mr. Braid, the trial was made under the direct superintendence of a British Officer, a period of nine days having been stipulated-for on the part of the devotee; but this was shortened to three at the desire of the Officer, who feared lest he should incur blame if the result was fatal.—The appearance of the body when first disinterred, is described in all instances as having been quite corpse-like, and no pulsation could be detected at the heart or in the arteries; the means of restoration employed were chiefly warmth to the vertex, and friction to the body and limbs.—It may be remarked that the possibility of the protraction of such a state (supposing that no deception vitiates the authenticity of the narratives referred-to) can be much better comprehended as occurring in India, than as taking-place in this country; since the warmth of the tropical atmosphere and soil would prevent any serious loss of heat, such as must soon occur in a colder climate, when the processes whereby it is generated are brought to a stand.

* Several such cases are recorded in Dr. H. Mayo's "Letters on the Truths contained in Popular Superstitions," and also by Mr. Braid, Op. cit.

muscle retains its irritability and remains free from rigidity, so long we may say with certainty that it is *not dead;* and the persistence of its vitality for an unusual period affords a presumption in favour of the continuance of some degree of vital action in the body generally; whilst, on the other hand, the entire loss of irritability, and the supervention of rigidity, afford conclusive evidence that death has occurred. The most satisfactory proof, however, is given by the occurrence of *putrefaction;* this usually first manifests itself in the blue-green coloration of the cutaneous surface, especially the abdominal; but it speedily becomes apparent in other parts, its rate being usually in some degree of accordance with the external temperature, though also much influenced by the previous condition of the solids and fluids of the body, these having been sometimes left by diseased actions in a state that renders them peculiarly prone to disintegration (§ 60).

881. With the final restoration of the components of the Human Organism to the Inorganic Universe, in those very forms (or nearly so) in which they were first withdrawn from it, the Corporeal Life of Man, of which it has been the object of the foregoing Treatise to sketch the leading features, comes to a final close. But the Death of .the Body is but the commencement of a new Life of the Soul; in which (as the religious physiologist delights to believe) all that is pure and noble in Man's nature will be refined, elevated, and progressively advanced towards perfection; whilst all that is carnal, selfish, and degrading, will be eliminated by the purifying processes to which each individual must be subjected, before Sin can be entirely subjugated, and Death can be completely "swallowed up of Victory."

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